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Department of Defense in the war on drugs: an optimization model for counter-narcotics assets

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THESIS

DEPARTMENT OF DEFENSE IN THE WAR ON DRUGS:
AN OPTIMIZATION MODEL FOR
COUNTER-NARCOTICS ASSETS

by

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by

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ABSTRACT

This study explores the optimization method of simulated annealing for use in an analytic tool for counter-narcotics analysis. A model is developed, employing RAND Corporation's Simulation of Adaptive Response model as an objective function evaluator, which optimizes interdiction asset locations relative to a sample smuggling network in the Caribbean region. In addition to asset location optimization, the response of the model to changing numbers of assets is also tested. Results indicate that this methodology has potential for use in the counter-narcotics program, and perhaps other network interdiction applications. Further research and testing are recommended. Military drug interdiction and the smuggling threat are discussed.

THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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I. INTRODUCTION

A. BACKGROUND

The Defense Authorization Act of 1989 designated the Department of Defense (DoD) "as the single lead agency of the Federal Government for the detection and monitoring of aerial and maritime transit of illegal drugs into the United States." The Act also tasks DoD with expanded support to civilian Law Enforcement Agencies (LEA's) involved in drug interdiction. According to Secretary of Defense Dick Cheney,

> The Department of Defense is an enthusiastic participant in the nation's drug control effort. We have significant resources at our disposal. We can make a substantial contribution to our national effort if we use our assets intelligently and efficiently. [Ref. 1: p. 4]

To these ends, the President's *National Drug Control Strategy* for 1991 estimated the DoD budget for drug interdiction at nearly $1.1 billion, more than double the actual expenditures for 1989. Obviously, the potential contributions by DoD are being taken very seriously.

In 1988, the RAND Corporation developed the Simulation of Adaptive Response (SOAR) model to analyze the effect of military involvement in drug interdiction. SOAR is a stochastic network simulation of drug smuggling involving theoretical routes for drug shipments and the response of smugglers to being interdicted. Expanded involvement of the military in drug interdiction was evaluated by examining the effect that increased interdiction probability on the theoretical routes might have on the import price of illegal drugs. The conclusions of the authors of the RAND study (Gordon Crawford, Peter Reuter, et al.) were not heartening. Although the limitations of the SOAR model caused it to be biased toward successful interdiction, it was found that "interdiction must be very stringent indeed to greatly affect U.S. drug consumption." [Ref. 2: p. 73] However, the model is simplistic in its approach to smuggling routes and the presence of interdiction forces. Routes are not associated with actual geographic areas due to a lack of available data, while interdiction assets are represented solely by a probability of interdiction on the generic routes. This simplicity leaves room for expansion of the model and further analysis.

B. PROBLEM ANALYSIS

Government-sponsored studies prior to that undertaken by RAND did not concentrate on the adaptation of smugglers, nor explicitly examine the potential for military contribution to the drug interdiction program [Ref. 3: p. 4]. As part of a comprehensive study, SOAR was designed to aid in a policy analysis of the overall interdiction program.

As a policy tool, SOAR did not require a geographic structure or specific representation of interdiction assets. For this reason, SOAR is not useful in operational planning or analysis. RAND's conclusions, at a policy level, indicate that military involvement in drug interdiction may have limited effectiveness [Ref. 3: p. 130]. However, the Department of Defense has a major role in the program, and would benefit from the availability of an analytic tool which could be used to evaluate the effects of operational planning and to explore, with a consistent measure, the effectiveness of different force and capability alternatives.

Interdiction problems are frequently modeled as flow networks for which optimization methods are used to determine which arcs or nodes should be cut or removed to provide an optimum result. In the case of a smuggling network, transit routes may be represented by arcs which are not well defined, or are completely unknown to the interdictors, making it difficult to entirely sever the arc. Even if it were possible, the smugglers themselves will eventually realize that the arc has been cut and will move to another route, adapting their methods to the interdiction. The SOAR model simulates this type of response on the part of drug smugglers, making it a fairly obvious choice to measure the effectiveness of interdiction on a smuggling network.

Because routes used by smugglers may not be clearly defined, it is unrealistic to merely place assets on arcs representing segments of the routes. By developing a geographic structure for the routes, assets can be located by latitude and longitude, and the effects of assets on the routes (i.e., the probability of interdiction on routes) can be measured as a function of their range from the routes. This also would allow assets to affect multiple routes, for example, routes passing through a geographically restricted area, or chokepoint. Finding the optimum locations for assets relative to a smuggling network with stochastic flows will be difficult. As the locations of assets change, flows through the routes will also change, resulting in local and global optima which vary with the locations of assets. There are also likely to be many such optima, a result of different assets contributing the same probability of interdiction to routes or being located in positions previously tested by other assets. In addition, the number of possible locations for assets is infinite, requiring some control over the locations tested if discrete optimization is to be used. This control must include geographically feasible areas, but should also reflect operational constraints, such as a requirement for certain assets to operate within a set range from each other or a base, and political constraints, such as foreign airspace or waters restrictions.

An optimization model with the properties described in this analysis, which retains enough realism to be considered valid, would be of great benefit at the operational level of the military drug interdiction program.

C. METHODOLOGY

We will propose a solution to the need for an analytical tool which may be used for analysis and planning at the operational level of the military drug interdiction program. An exploration of the use of simulated annealing to optimize the location of counter-narcotics assets with respect to a drug smuggling network is presented. The objective function is an outcome of the modified SOAR model, in which the routes used by the smugglers are modeled with a geographical structure, and the physical location of interdiction assets (eg. ships, aircraft, aerostat balloons, observation posts, etc.) are used to determine the probability of interdiction in an area. From the SOAR model we extract the total cost to smugglers, a measure of effectiveness for one major goal of the overall drug interdiction program, reduction in consumption of illegal drugs. Interdiction raises the risks involved with drug smuggling, thereby increasing the costs associated with personnel pay, equipment and drug replacement, etc. Eventually, this results in higher consumer prices for drugs. Economically, higher prices should cause a decrease in demand for drugs in the long run, that is, lower consumption by Americans. Increased crime among addicts to compensate for higher prices is not addressed.

Use of SOAR as the objective function evaluator in a model which exhibits numerous local and global optimal asset locations eliminates the potential use of gradient-optimization methods. It is for this reason that we chose to apply simulated annealing as the optimization method to maximize the total cost to the smugglers.

D. SCOPE

This thesis briefly discusses the flow of cocaine from South and Central America into the southern United States, and the role the Department of Defense plays in interdiction efforts within this geographical area.

The model presented is capable of evaluating the use of assets in the Atlantic, Pacific and Southwest Border regions; however, for the numerical results presented in this thesis, only routes and assets in the Caribbean and Gulf of Mexico are examined. Much of the information that is available about known smuggling routes and the assets involved in counter-narcotics operations is highly classified. In the interest of maintaining an unclassified example, some data used in the model is taken from the original SOAR model, while information on smuggling routes and counter-narcotics assets is intended to be representative only, and should not be construed as data representing actual circumstances.

II. THREAT AND INTERDICTION EFFORTS OVERVIEW

A. CURRENT THREAT OF ILLEGAL DRUG TRAFFICKING

A number of indicators show that progress has been made in the war against drugs. Overall drug use, drug-related medical emergencies, and student attitudes toward drug use have all declined past the goals set in the 1989 National Drug Control Strategy, shown in Table 1. [Ref. 4: p. 5]

Table 1 NATIONAL DRUG CONTROL STRATEGY NATIONAL OBJECTIVES: Statistical significance ranges from 1 to 30%.

	GOAL	ACTUAL
CURRENT OVERALL DRUG USE	- 10%	- 11%
CURRENT ADOLESCENT DRUG USE	- 10%	- 13%
OCCASIONAL COCAINE USE	- 10%	- 29%
FREQUENT COCAINE USE	50% reduction in rate of increase	- 23% actual decline
CURRENT ADOLESCENT COCAINE USE	- 20%	- 49%
DRUG-RELATED MEDICAL EMERGENCIES	- 10%	- 18%
STUDENT ATTITUDES TOWARD DRUG USE	- 10%	- 28%

Cocaine-specific indicators showed decreased purity and significantly higher prices in many areas of the country for the past year. Also, since 1985, "... reported current cocaine use (use in the past month) decreased some 72 percent." [Ref. 5: p. 1]

The effect on smugglers themselves may be deduced from the surrender of a number of Colombian drug lords and the level of effort smugglers put forth to get their product into the United States. Examples of this effort include the tunnel between Mexico and Arizona discovered in May 1990 [Ref. 6: p. A1] and the occasionally high tech hiding places used in vehicles, boats, and aircraft.

On the other hand, many problems still exist which illuminate the threat to national security declared by President Reagan in 1986. Drug-related violence and murders remain at high levels within the United States, as does the amount of cocaine being produced throughout South America. Table 2 displays production levels for the three major producing countries from 1988 to 1990, the last year for which data was available.

Table 2 COCAINE PRODUCTION ESTIMATE: Potential Cocaine HCl Production by Country (tons). Sources: NNICC Reports, 1989 and 1990.

	YEAR		
COUNTRY	1988	1989	1990
PERU	242	440-468	440-473
BOLIVIA	112	264-458	259-435
COLOMBIA	43	77	72
TOTAL	397	781-996	771-980

Smugglers' high tech methods display their increasing adaptability to interdiction efforts, as well as the effects of interdiction. Some smugglers are showing that they are willing (or crazy enough) to take on interdiction forces, as evidenced by incidents along the border with Mexico where smugglers have exchanged small arms fire with U.S.

military forces [Ref. 7: p. 1], and the attempt in April 1990 by smugglers linked to the Medellin cartel to buy Stinger missiles [Ref. 8: p. 3].

The evolution of narco-terrorism may be proof enough that we are indeed facing a war which must be fought by our armed forces outside the United States. Many revolutionary/terrorist organizations, such as M-19 and FARC in Colombia and Shining Path in Peru, are intimately linked to the drug trade, forming the basis for this narco-terrorism. These groups have shown decided anti-American leanings, and have used violence and threats against high level U.S. officials. One-time M-19 leader Ivan Mariano Ospina said in December 1984, "May these threats be carried out and may they be carried out in the entire world against the rapacious imperialism that lives at the cost of misery of exploited people...." [Ref. 9: pp. 36,37] Even state leaders have been involved, most recently illuminated by General Noriega in Panama, but also including Fidel Castro who has acknowledged the use of cocaine as a weapon, "We are going to make the people up there (the United States) white, white with cocaine [Ref. 9: p. 32]."

Clearly, there are some signs of success in the drive to reduce illegal drug trafficking and abuse. However, it is also plain that much more effort is required in all phases of the *war on drugs* before the situation can be considered under control, let alone resolved. Involvement of the Department of Defense in reducing the flow of drugs into this country is only one part of the overall struggle, but, as Secretary Cheney said, the military can have a great impact in this effort.

B. WHAT IS DOD'S INVOLVEMENT NOW?

Since the Department of Defense's first, somewhat reluctant, involvement in counter-narcotics in the 1970's, the military has been called upon for increasing support each year. The Defense Authorization Act of 1989 presented DoD with a primary role in the drug war. We now see all segments of the military accepting counter-narcotics assignments, including operational missions, such as ship and aircraft patrols with embarked law enforcement personnel, intelligence gathering and surveillance, and material support. The overall DoD chain of command for counter-narcotics is shown in Figure 1.

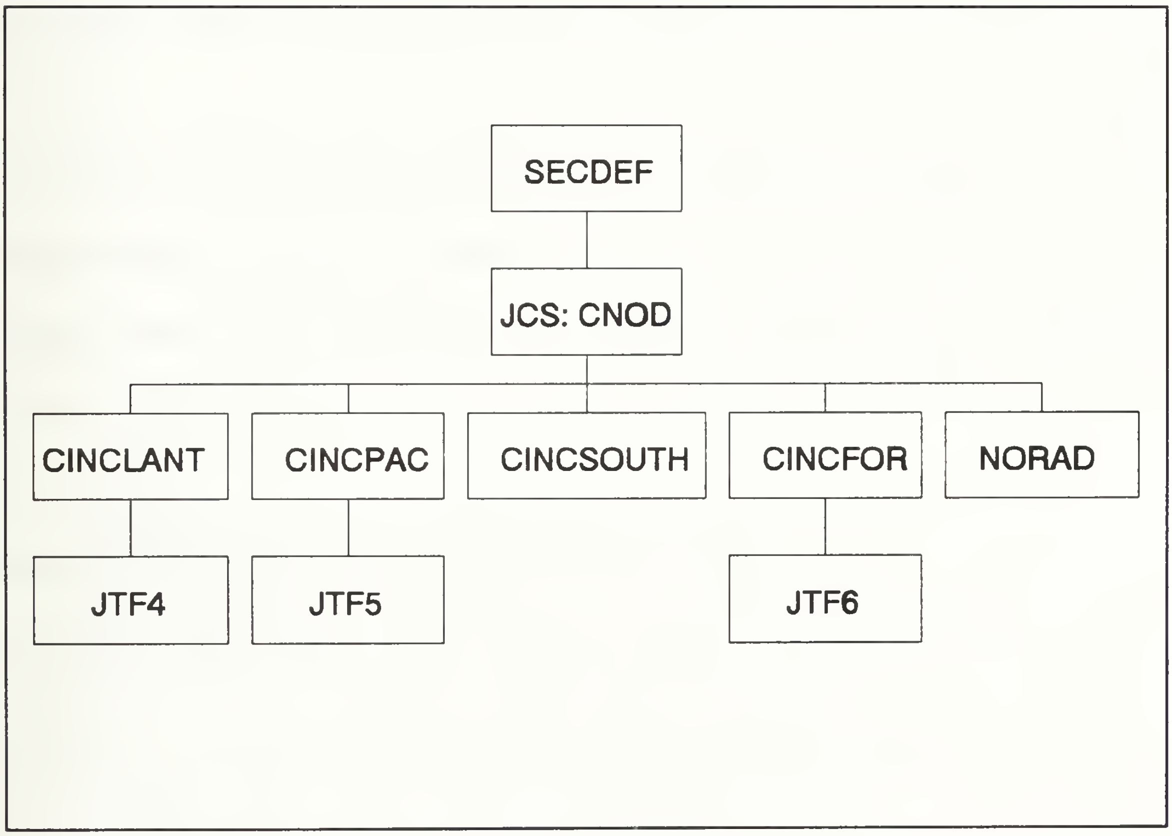


Figure 1 DoD Counter-narcotics Chain of Command.

Obviously there is high-level attention being paid to the problem. The three Joint Task Forces command the military assets involved in actual day-to-day interdiction operations.

1. Joint Task Force 4

Located in Key West, Florida, JTF4 is in charge of operations in the Atlantic area of responsibility (AOR). As the first Joint Task Force, their mission included the creation of a joint fusion center for tactical intelligence and the communications necessary to assemble the data and provide a finished product to all users. JTF4 conducts their own detection and monitoring operations in the Atlantic AOR, and coordinates the operations of other agencies, such as the Coast Guard, Customs Service and local law enforcement activities.

Although JTF4 has no dedicated assets, they do have tactical control of various personnel, ships, patrol and intercept aircraft, and intelligence collecting assets assigned from other DoD commands, the Coast Guard and Customs Service. [Ref. 10: p. 78]

2. Joint Task Force 5

Located in Alameda, California, JTF5 has a similar responsibility and mission in the Pacific AOR as that of JTF4 in the Atlantic. They conduct organic operations to detect and monitor aircraft and surface vessels suspected of smuggling, as well as coordinating other agencies' operations within their AOR. JTF5's mission includes integrating into the intelligence communications network and providing drug-related intelligence to law enforcement agencies as appropriate. [Ref. 11] As is the case with JTF4, JTF5 has no dedicated assets, but takes tactical control of various assets assigned from DoD commands, the Coast Guard and Customs Service.

3. Joint Task Force 6

Located at Ft. Bliss, Texas, JTF6 has a much different mission from that of JTF's 4 and 5. Specifically, "Joint Task Force Six plans and coordinates all DoD support requested by Federal, State and local law enforcement agencies within the Southwest Border region." [Ref. 12]

Requests for support usually come through Operation Alliance, an agency comprised of representatives from Federal, State, and local law enforcement agencies of the Southwest Border states: Texas, New Mexico, Arizona, and California. Support provided includes observation posts, reconnaissance, *terrain denial* operations designed to deter smugglers from using areas along the border, training teams, military drug detection dogs, and construction. Personnel from all military services and various National Guard units have been called upon to perform these functions.

C. WHERE MAY DOD'S INVOLVEMENT LEAD?

There are as many different opinions concerning DoD's future involvement in drug interdiction as there are people contemplating it. These opinions range from complete disassociation to complete involvement in all aspects, not just detection and monitoring. Many rational, and some not so rational, arguments are given for both extremes and everything in between.

One of the main arguments against the use of military forces in counter-narcotics is the Posse Comitatus Act (Title 18 U.S. Code, Section 1385), which prohibits the direct use of military forces for civil law enforcement activities within the United States. Because of this law, military forces involved in drug interdiction operations may not perform search and seizure or make arrests. The military is limited to its monitoring and detection mission and support of law enforcement activities.

Another strong argument is that drug interdiction operations have a detrimental effect on DoD's primary mission to maintain a military capable of fighting a war to defend the U.S. or its interests. This argument contends that the fight against drugs is not truly a *war*, and that performing area patrols and ship boardings, detection and intercept of slow moving aircraft, and patrolling a border area are not suitable training operations for the military. Following the end of the Cold War (i.e., the reduction of the Soviet threat) drug smuggling takes its place among "principle threats ... that replace the old Soviet threat." [Ref. 13: p. 18] This means that drug interdiction operations need no longer be construed merely as training evolutions, but are actually part of the military's primary mission.

A third argument is the cost of military drug interdiction operations. It was estimated that the Air Force spent approximately $433,000 per drug bust in 1986. [Ref. 14: p. 7] Many believe that the $1 billion-plus military drug interdiction budget could be better spent on education and treatment programs. These programs are extremely important, since interdiction alone cannot halt the problem of drug abuse. However, education and treatment are more effective when drugs are more expensive and less readily available. "Most leaders of prevention and treatment programs recognize this; their task is made easier when drug enforcement works." [Ref. 15: p. 3] The goal of interdiction is to "complement and support our international drug control activities and domestic law enforcement programs, ... to create an integrated supply reduction program." [Ref. 15: p. 65] Interdiction functions not only to seize drugs destined for the U.S., but to act as a deterrent to potential drug smugglers, and to force the price of illegal drugs to rise through increased risks the smugglers face. In addition, "Interdiction provides a highly visible sign to other nations of U.S. interest in reducing drug use." [Ref. 3: p. 2] This is a typical extension of the age-old Navy mission of *showing the flag*. Thus, the cost per seizure of military interdiction operations does not encompass the whole military contribution to the overall drug control strategy.

Plainly, the military has an important role to play in combatting the drug problem faced by the United States. While no one wants to see the military take on civilian law enforcement roles, DoD has the manpower, assets, technology, and money to assist and supplement Federal, State, and local law enforcement agencies in reducing the supply of drugs.

While DoD maintains its role in detection and monitoring of illegal drugs entering the country, there are many who are pushing for an even greater military involvement. In 1990, Senator Mitch McConnel (R-KY) proposed a plan for shooting down suspected airborne smugglers who refuse to land for inspection [Ref. 16: p. A19]. Although this plan was not put into effect, it did have a large amount of support. Military and LEA personnel are providing training and technical assistance for anti-drug and counterterrorist forces in a number of production and transit countries. Operation Bahamas, the Turks and Caicos Islands (OPBAT), a multinational strike force in place since 1983, has been very successful in preventing smuggling flights into the Bahamas. It is certainly conceivable that similar strike forces could be established with other countries.

The completion of the aerostat balloon network and the Caribbean Basin Radar Network, as well as proposed over-the-horizon radar systems, would significantly increase the ability to detect and monitor air traffic in smuggling areas, and act as a deterrent to smugglers. Aerostats are tethered radar-equipped balloons, flown at about 10,000 feet, which "provide surveillance of oceanic and land areas right down to the surface." [Ref. 17: p. 7], with a range of approximately 200 nautical miles. The Caribbean Basin Radar Network is a series of ground based radars designed to provide nearly complete coverage of the Caribbean basin. Figure 2 displays the proposed coverage of the aerostat network [Ref. 18: p. 84].

RADM Walter Leland, USCG, said, "We know that when the aerostats are flying the traffic stops." [Ref. 19: p. 7] However, there are widely differing reports on the operational reliability of the aerostat balloons. Some Air Force and Customs Service officials call the system too expensive and fragile, claiming the balloons are <u>not</u> operational more than 60% of the time because of severe weather and maintenance problems [Ref. 20: p. 15]. At the same time, Pentagon figures showed the balloons to be operational 70-75% of the time. [Ref. 21: p. S14] Such discrepancies cast doubt on the effectiveness of

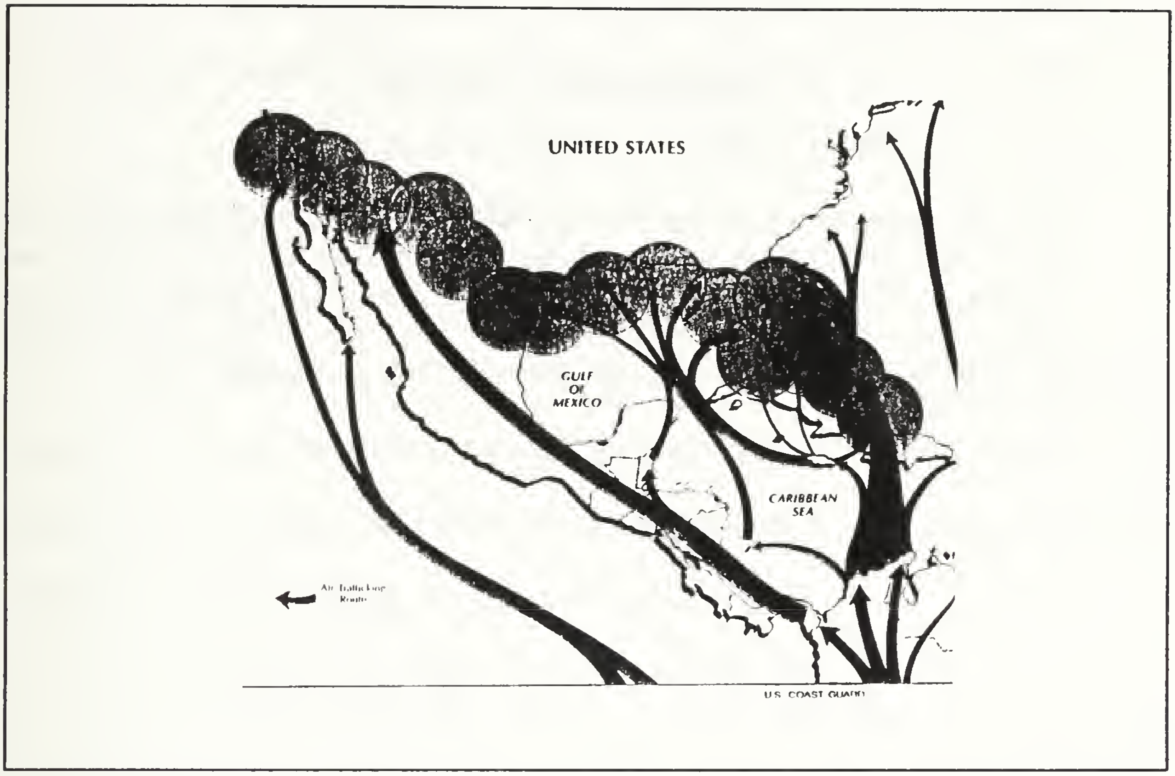


Figure 2 Aerostat Radar Network.

these systems, in turn making it harder to get funding to continue and expand the program.

Finally, there have been a number of popular novels recently published which provide more speculation about the possibilities of the military's future role in drug interdiction. Most notable of these are Tom Clancy's *Clear and Present Danger* and Dale Brown's *Hammerheads*.

Although many widely ranging proposals for military involvement in counter-narcotics and numerous arguments against any use of the armed forces in drug interdiction exist, with the current trend toward downsizing the armed forces it is difficult, if not impossible, to predict exactly what DoD's future role in the nation's drug control strategy will be. It is fairly certain however, that the U.S. military will continue to be involved. A recent report by Rep. Les Aspin (D-Wis.), Chairman of the House Armed Services Committee, foresees the continuation of a military role:

> The drug problem must be attacked from both sides -- both the demand for drugs and the supply of drugs must be reduced.... Although the United States will continue to rely primarily on nonmilitary means in its effort to curtail the international trade in drugs, Americans will also want U.S. military forces engaged in the struggle with drug traffickers, primarily in an interdiction role.
> [Ref. 13: p. 17]

III. SIMULATION MODEL

A. THE ORIGINAL SOAR MODEL.

1. Background.

The Simulation of Adaptive Response (SOAR) model is part of a RAND Corporation study on the drug interdiction program, undertaken at the request of the Under Secretary of Defense for Policy in February 1986. This study culminated with the publication of analysis results in three RAND reports.

The primary conclusion of RAND's effort was that:

> Increasing drug interdiction efforts are not likely to greatly affect the availability of cocaine in the United States....This conclusion is driven primarily by the small share of total drug distribution costs that are accounted for by the smuggling sector. Only about 10 percent of the final price of cocaine comes from smuggling costs and profits. [Ref. 3: p. xi]

This conclusion does not take into account other reasons for military involvement in drug interdiction, such as those discussed in the previous chapter. It does, however, suggest that the need exists for a tool to be used in counter-narcotics analysis. RAND's SOAR model provides a reasonable starting point for developing such a tool.

2. Model Description.

SOAR is a dynamic network simulation which allows drug smugglers a number of air, sea, and land smuggling routes. These routes are generic in that they are not associated with particular geographic routes. The route used for a particular shipment of drugs is probabilistically selected, depending on the costs of shipping drugs via that route and the expected risk costs for shipping via the method associated with that route based on a perceived probability of the shipment being seized. This probability is estimated by a time-weighted history of unsuccessful shipments on that route, and will change with time as shipments succeed or are interdicted.

Time between shipments is an exponential random variable with an input mean. The quantity of each shipment is an input constant, as are the capacity and costs of the routes and shipping methods. SOAR does not attempt to model the adaptation of changing shipment sizes in response to interdiction severity. The capacity of the route and the size of the shipment are used to determine the number of trips that each shipment will require. These trips occur on the same route at the same time, leading to a saturation factor which increases the probability that the shipment is seized.

Interdiction in SOAR is modelled by a general probability of interdiction for each route. "Military resources are treated...simply as means for augmenting particular activities, thereby raising the probability of success in those activities." [Ref. 3: p. 8] This probability is an input value and can be changed for predetermined time periods (phases). When multiple trips are required, the probability of interdiction on the route, for that shipment, is increased as a result of the saturation factor.

The smugglers' overall goal is to ship as large a quantity of drugs as possible at their perceived lowest cost. Costs to the smuggler include the cost of the drug, operating costs for the method of shipment, the cost of replacing lost assets if a shipment is seized, and pay to personnel. Smuggling personnel are assumed to be risk averse, therefore pay is assumed to change as the square of the perceived risk involved in using a particular route. Increasing interdiction rates will affect the overall cost to the smugglers by raising each of these costs.

For their model, the RAND authors attempted to estimate:

- Quantities shipped, by route, in a given year.
- Number of shipments, by route, in a given year.
- Number of vessels identified as suspicious, by route, in a given year. Of those, the number pursued, by route in a given year. Of those, the number resulting in seizures, by route, in a given year.
- Estimates of the compensation resulting from the likelihood of prison.
- Estimates of smugglers' nonrisk compensation and profits. [Ref. 2: p. 9]

As can be expected, little concrete data was available, resulting in the use of informed guesses for many of the input parameters.

Output of the model includes an echo of the input parameters and the statistics described in Appendix A, Sections A.2. and B.1. respectively. The output is an average of an input number of runs desired. Ten runs were used in the RAND analysis, providing "an adequately precise estimate of the overall means, especially compared with the imprecision of some of the input data and some of the assumptions incorporated in the model." [Ref. 2: p. 24] This output was not used in our analysis, but is included in the appendix for information.

Computational details of the SOAR model are described in Chapter IV of *Simulation of Adaptive Response*, and are reasonably easy to interpret from the model itself.

B. THE SOAR SIMULATION AS THE OBJECTIVE FUNCTION EVALUATOR.

1. Measures of Effectiveness.

In evaluating drug interdiction efforts, many measures of effectiveness have been proposed. Civilian law enforcement agencies are concerned with numbers of seizures and smugglers prosecuted. News reports regularly include the street value of drugs seized. Because of its unique role of detection and monitoring and support to law enforcement, and the fact that the armed forces are prohibited from direct participation in the arrest and seizure phases of interdiction, the military's measure of effectiveness (MOE) is based on the number of supporting missions provided. This MOE is not very useful for a model which attempts to find optimal locations for interdiction assets. Although it indicates the level of military support to reducing the flow of drugs into the United States, it provides no quantitative measure of the effectiveness of the overall drug interdiction program.

The quantity of drugs seized is a popular MOE, as it provides an evaluation of how much drugs are prevented from entering the country. However, it is possible that, when interdiction efforts are most successful, no drugs at all would be seized. That is, shipments could be deterred, smugglers could be forced to use the most expensive methods of shipping to avoid interdiction, etc.

The major goal of drug interdiction is to reduce the consumption of illegal drugs. Military assets are an integral part of increasing the effectiveness of interdiction, thereby helping to achieve this goal. In addition to seizing drugs and equipment, interdiction increases the risks which smugglers face and causes them to change their methods of operation. All of these effects of interdiction result in higher costs to the smugglers, costs which are eventually passed on to the consumers of illegal drugs. Although some users are likely to be insensitive to increased drug prices, "the body of economic support for a relationship between price and consumption is too strong to allow much doubt that, at least in the long run, higher prices will lead to lower consumption." [Ref. 3: p. 20] Therefore, if it can be measured or estimated with some confidence, cost to the smugglers is an MOE which reflects the overall goal of the drug interdiction program.

As computed by the SOAR model, total cost to the smugglers includes the costs of unsuccessful shipments, thereby incorporating the MOE of the amount of drugs seized. Parameters for an alternate objective function value could easily be extracted from the simulation, or the optimization algorithm could be applied to any desired objective function.

The simulation used as the objective function evaluator for the optimization model presented in this thesis is a slightly modified version of the original SOAR model. The changes involve the attempt to model smuggling routes with a geographical structure and calculating the probability of interdiction based on the location of military assets.

2. Model Assumptions.

In any model, many simplifying assumptions are required. This is especially true in attempting to model a process of this scale. Perhaps the biggest assumption lies in the use of the SOAR model outcome as the objective function to be optimized. That is, we assume that the simulation provides a reasonable estimate of the total cost to the smugglers. This includes accepting as reasonable the assumptions made in constructing SOAR, which are described in the RAND publications.

Another major assumption involves modelling the drug smuggling routes. Except for the natural chokepoints in the Caribbean, little is known about the exact routes being used. Therefore, the routes presented in this model are assumed to be representative of area routes of unknown width. In the Mona Passage, Yucatan Channel and other chokepoints, the width of sea routes is constrained by the presence of land on either side. However, in the Pacific, Southwest Border area, and for many air routes, the width could be hundreds of miles. Assets which provide coverage of a route are assumed to be patrolling the area which that route represents. Figure 3 displays a general idea of smuggling routes as interpreted by the Drug Enforcement Agency.

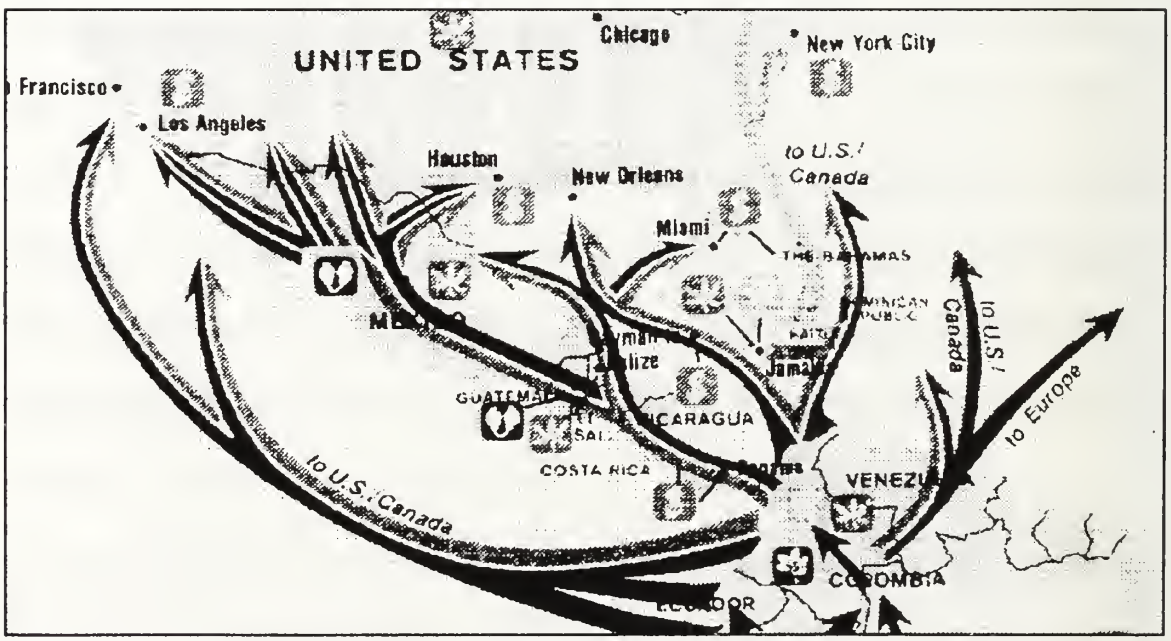


Figure 3 Drug flows from South America into the United States.
Source: DEA Map 1 - 1987 (Revised 1989)

A third assumption is made when computing the probability of detection on the routes. Each asset represents a sensor which adds a probability of interdiction to the route that it covers. It is also assumed that an asset covering a leg of the route acts independently of other assets on that and other legs, and that detection on any leg of a route can be taken as an event independent of all other legs on that route. Realistically, a patrol aircraft on a route, which detects a suspicious surface contact is likely to be in either direct or indirect contact with a surface asset on that leg or a subsequent leg, giving information about the presence of that contact to the surface asset and increasing the surface asset's probability of detecting and interdicting that contact. Similarly, a surface asset may detect a suspicious aircraft and report it, etc. For modeling purposes, however, we believe these assumptions to be reasonable. Independence between assets and routes will result in SOAR providing an upper bound on the measure of effectiveness. This consequence should be considered when estimating the probabilities of interdiction input to the model for each asset type against each method of smuggling.

3. Data Structures and Computations.

a. Smuggling Routes.

The representation of routes is accomplished using a hierarchical adjacency list of geographical points. The geographic points are listed in a data file similar to that shown in Appendix A Section A.5., which includes points of origin for drug shipments, intermediate route points, and points of entry into the United States.

The information for the routes themselves is taken from another data file. A description of the inputs and an example of the data file are in Appendix A Section A.3.

b. Assets.

Appendix A Section A.4. describes the input information and a data file for interdiction assets. Although we have listed assets as SHIP1, PAIR1, etc., *asset* need not necessarily refer to a single ship, aircraft or ground unit. An asset may be considered whatever mix of elements is required to achieve the range and probability of interdiction input to the model. For simplicity, we will continue to refer to assets as single units. Asset types are used to describe assets with the same range and probability of interdiction. By assigning additional asset types, the matrices containing this information could be expanded to include unique input data for particular assets.

c. Computation of route probabilities.

A shipment of drugs will be interdicted on a particular route with a probability computed in the subroutine PROBCOMP. In this subroutine, the legs of each route are checked to determine if assets are located such that the leg falls within the range of the assets. Up to this range, the asset contributes a constant probability of interdiction to the route. Beyond this range, the probability decays exponentially as a function of the additional distance. The probability of interdiction on a route is then computed as simply the combination of independent probabilities for all assets covering all legs of the route.

The probability decay function chosen results in probabilities for individual assets decreasing to approximately 13.5% of the original value at twice the asset range. For example, an asset with a given constant probability of 0.10 to 100 miles will have a probability of interdiction equal to 0.0135 at 200 miles. This method of computing probabilities can be supported by considering the given range of an asset as that area which can be patrolled with a constant probability, and exponential decay of the probability representing the decreasing effectiveness of the patrolling as the distance between the asset and the route increases past that range.

IV. THE ANNEALING MODEL

A. GENERAL DESCRIPTION

The simulated annealing method is so-called for its resemblance to the annealing of solids, in which a material is heated to the point where all particles arrange themselves randomly in the liquid phase, and is slowly cooled so that all particles arrange themselves in the low energy ground state of a corresponding lattice. [Ref. 22: p. 2]

The method starts at either a predetermined or random initial point. In the feasible space of the independent variables, a random walk samples the objective function [Ref. 23: p. 210] (analogous to the energy state of a physical system). Each step providing an improved objective function value is automatically accepted. Steps which are detrimental to the objective function value are accepted according to a Boltzmann probability function, $p = \exp(-\Delta E/K_B T)$, which is dependent on the energy and temperature of the physical system. This allows the path to walk out of local and global optimal points [Ref. 23: p. 211]. The process is often called a *Metropolis loop*, named for the author who used a model simulating the evolution of a solid to thermal equilibrium in 1953 [Ref. 24: p. 14]. Obviously, the algorithm could run indefinitely, walking in and out of the global optima. One way to prevent this from happening is to specify the number of steps the algorithm is to take. However, this in no way guarantees reaching the global optimum. Recently much research has been put into developing cooling or annealing schedules. Essentially, such schedules decrease the probability of accepting a detrimental step by decreasing the temperature of the system as the global optimum point is approached. The random walk is terminated when a predetermined number of successive trials does not produce an acceptable objective function value. [Ref. 23: p. 212]

B. APPLICATIONS

The simulated annealing method has been applied to optimization problems in numerous fields, including physics, operations research, numerical analysis, biology, materials science, game theory, code design, etc. [Ref. 22: p. 14].

There are many advantages and disadvantages associated with the simulated annealing method. The algorithm is applicable to many different optimization problems and is easy to implement. The greatest disadvantage is the potentially prohibitive amount of time required to converge to a near-optimal solution. This is dependent on the cooling schedule and the step size used in the random walk. [Ref. 25: p. 91]

C. THE GENERALIZED ANNEALING ALGORITHM

As stated previously, simulated annealing algorithms have been used almost exclusively in applications which minimize the objective function. The probability function is especially well-suited to cases where the objective function minimizes to zero, or where the optimal value is known. In these cases the probability of accepting a non-improving step is driven to zero as the optimum is approached.

In the case where the optimal value is not known, the typical algorithm calls for selecting some initial estimate of the optimal value (ϕ_m) and allow the random walk to sample the objective function value (ϕ), continuing until $\phi - \phi_m$ becomes negative, then decrease ϕ_m repeating this process as required. On the other hand, if the initial estimate of ϕ_m is too low, it is increased as part of the cooling schedule, so that $\phi - \phi_m$ will approach zero. [Ref. 23: p. 213]

We have attempted one of many possible applications of this method to a maximization problem, by taking an initial guess for the optimum as an input value, as well as the number of steps to be taken before reducing the guess. Cooling the guess (ϕ_m) is accomplished by keeping track of the highest value found so far (ϕ_B), and reducing ϕ_m according to the function $\phi_{m+1} = \phi_m - \alpha * (\phi_m - \phi_B)$, where α is a predetermined fraction which controls the cooling speed. This ensures that ϕ_m is never reduced past the best value found in the random walk. If the random walk produces a value which is greater than either the current ϕ_m or the input guess, then both are increased a significant amount above the higher value (we have chosen $\phi_m = 1.5 * \phi_B$). The cooling of ϕ_m again proceeds according to the previously described method.

In our application of the algorithm, we begin with a large step size (Δr) in order to sample a significant portion of the feasible region. As ϕ_m is reduced (or cooled) we also reduce the step size to a minimum value (Δr_{min}) by a similar equation, sampling a tighter area of the region. When a potential point of convergence is found, Δr is reduced to a small value (Δr_{low}) in an attempt to find an acceptable move in the very close vicinity. If an acceptable move is found, the step size is reset to the previous value (Δr_{old}), and the annealing continues.

This algorithm is not guaranteed to locate the objective function value associated with a global optimum. The value β in the probability function controls the rejection ratio, and will also determine, in part, how close to the optimal value the algorithm converges. For very low values of β, the algorithm will converge at, or very close to, the optimum, when the optimum value is known.

The feasible space and step generation used for our model are very simple, consisting of upper and lower limits on the latitude and longitude for asset locations, and random steps with size Δr. For example, we did not attempt to prevent assets from moving onto land, restricted airspace, or within search range of other assets. These are the more detailed geographic, operational, and political constraints, such as those discussed in Chapter I, Section B, which could be used to control possible asset moves. Such constraints could be represented in a subroutine that tests feasible locations and a set of rules controlling the possible moves of assets relative to each other.

Our algorithm, shown in Figure 4, is very similar to that presented by Bohachevsky, Johnson and Stein for a minimization problem allocating ballistic missile interceptors [Ref. 26]. The following terms used in the algorithm are defined:

- ϕ is the objective function value. A subscript of 0 indicates the current value, 1 indicates the value at the new location. Other subscripts are as defined above.
- Ω is the feasible space, that is, the set of latitudes and longitudes where assets may be located.
- $\mathbf{x}$ is the set of latitudes and longitudes for all mobile assets. A subscript of 0 indicates the current location, 1 indicates the new location.
- Δr is the step size. Subscripts min and low indicate the minimum step size used when cooling and the step size desired in attempt to find a more precise solution.

Step 1: Compute the objective function value for initial locations, ϕ_0.
Set ϕ_m = input guess.

Step 2: For each mobile asset, generate two independent standard normal random variates, A_1 and A_2, and compute the components of the random direction vector **d**:
$d_i = A_i/(A_1{**}2 + A_2{**}2){**}0.5$, i = 1,2.

Step 3: Compute candidate locations for assets, set $\mathbf{x}_1 = \mathbf{x}_0 + \Delta r * \mathbf{d}$.

Step 4: If the candidate locations are infeasible, ie, $\mathbf{x} \notin \Omega$, repeat Step 2.

Step 5: Compute the new objective function value, ϕ_1, and set $\Delta\phi = \phi_1 - \phi_0$.

Step 6: If the step increases the objective function value ($\Delta\phi \geq 0$), accept:
set k = 0, $\mathbf{x}_0 = \mathbf{x}_1$, $\phi_0 = \phi_1$, and n = n + 1.
If the step size has been reduced in Step 8 (k > S), reset step size $\Delta r = \Delta r_{old}$.
If $\phi_1 > \phi_B$, set $\phi_B = \phi_1$.

6a: Increase ϕ_m and initial guess if new objective function value is greater, ie,
If $\phi_1 > \phi_m$, set $\phi_m = 1.5 * \phi_1$.
If ϕ_1 > initial guess, set guess = $1.5 * \phi_1$.
Set n = 0.

6b: If N accepted steps taken (n > N), cool ϕ_m and the step size:
set $\phi_m = \phi_m - \alpha * (\phi_m - \phi_B)$ and $\Delta r = \Delta r - \alpha * (\Delta r - \Delta r_{min})$.
Set n = 0.

Go to Step 2.

Step 7: If the step is a decrease ($\Delta\phi < 0$), compute probability of acceptance and determine whether to accept or reject.
Set $p = \exp(\beta * \Delta\phi/(\phi_m - \phi_0))$. Generate a uniform random variate V.
If V > p, reject, set k = k + 1. If V < p, accept, set k = 0, $\mathbf{x}_0 = \mathbf{x}_1$, $\phi_0 = \phi_1$.

Step 8: If the stopping rule has not been reached (k < S), go to Step 2,
otherwise, if k = S, attempt to find a more precise solution with small step size, save current step size, $\Delta r_{old} = \Delta r$, set $\Delta r = \Delta r_{low}$, and go to Step 2.

Step 9: If the final stopping rule has not been reached (k < 2 * S), go to Step 2,
otherwise stop and return ϕ_0 as the optimal solution found.

Figure 4 Annealing algorithm to optimize interdiction asset locations relative to a stochastic network.

- β is the control parameter for the probability function (analogous to Boltzmann's constant).

- α is the fraction for reducing ϕ_m and Δr

- N is the number of accepted steps at each value for ϕ_m

- S is the stopping rule, the control for the number of attempted moves rejected before the solution is declared found.

- k is used to count the number of consecutive rejected moves

- n is used to count the number of accepted moves for each level of ϕ_m

The FORTRAN code for the model can be found in Appendix B.

D. RESULTS

The optimization model developed in this thesis was applied to a smuggling network of eleven air and sea routes in the Caribbean region. Figure 5 displays this network, formulated from the sample data sets in Appendix A. Some areas of the routes used are intuitive, for example, those running through the Yucatan Channel and the Mona and Windward Passages. However, these are meant to be illustrative of actual routes, and are not based on intelligence or other official information. The model was run on a number of different computers, SUN SPARC 1+ and 2 workstations, Tektronix 4336, Silicon Graphics IRIX, and an AMDAHL 5990-500 mainframe computer. The four UNIX systems yielded identical results, while the VMS-based mainframe computer found similar results to the UNIX systems.

Two applications of the model were tested. The first examined the locations at which the annealing algorithm converged. Ten runs each were performed with five

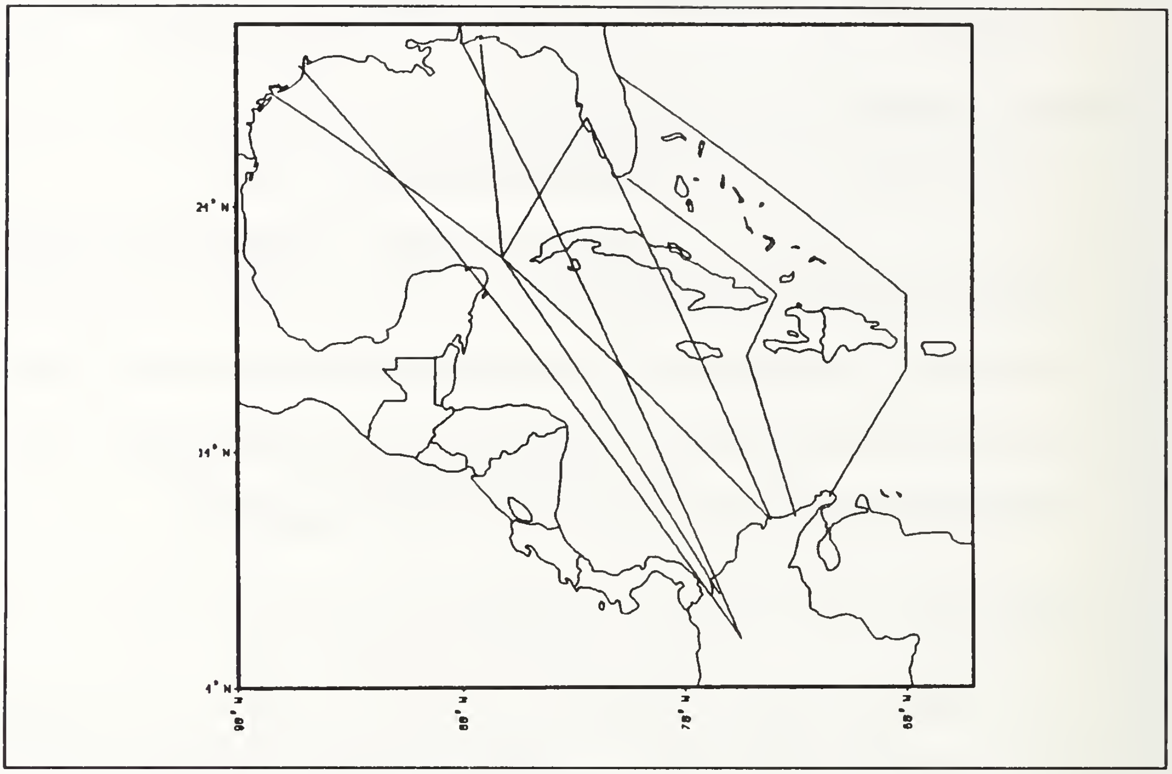
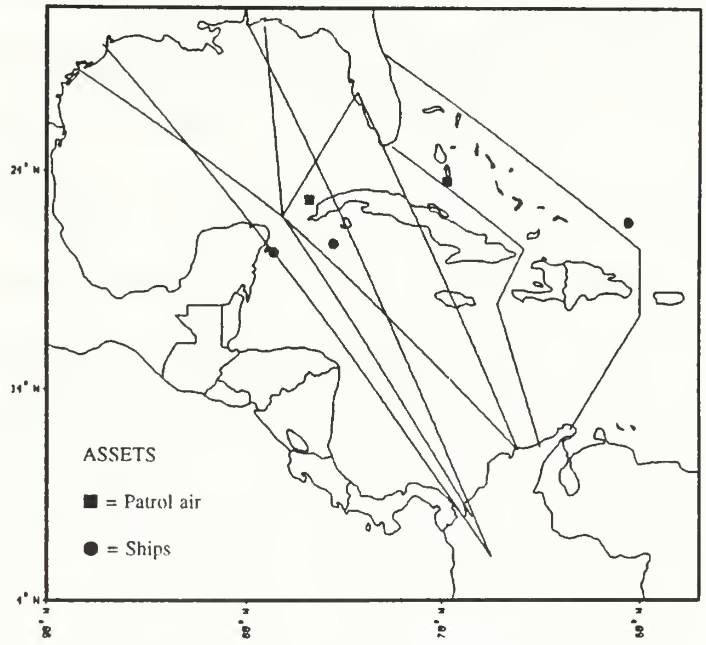


Figure 5 Sample Caribbean smuggling network

mobile assets, three ships and two aircraft. The resulting locations from one run are plotted in Figure 6. It is clear that some of the locations could easily be improved. This is due in part to the value of the probability function control parameter, β, used to ensure convergence of the algorithm in a reasonable amount of time. Each of the ten runs found different final locations, but all appeared reasonable and the optimal values found were similar, with mean equal to 75153.2 (dollars $\times$ 1000) and a standard deviation of 7204.1.

The second application explored the response of the model to a changing number of assets. Each run used equal numbers of ships and aircraft. Parameters of assets are from the sample data set in Appendix A. We found that the function,



Three ships, two aircraft
Optimal value = 78047

Figure 6 Results of five asset run (one of ten)

ϕ = 615430.6 - 71.07 * (80 - ASSETS) ** 2.07, determined using non-linear regression, fit the data well (R^2 = 0.9922). This particular function is dependent on the number of assets at the last data point, and is extremely simplistic, with total numbers of assets as the independent variable. Runs with more than 80 assets will change the parameters of this function, but will not significantly increase the maximum. Although the fit of the curve is good, the variance at each level of assets cannot be assumed equal, mainly due to the small sample size at the levels (2).

The regression model itself is not a fundamental result, but can be used to obtain useful information. With 80 assets we are very nearly saturating the routes, obtaining little additional benefit from adding assets. We will assume for the following discussion that 80 assets induce the highest possible total cost to the smugglers. In Figure 7 we have plotted a curve depicting the fraction of maximum value achieved versus assets. This fraction represents the regression function value divided by 615430.6, the function evaluated at 80 assets. From this, we see that 50% of the maximum attainable effect on the smugglers is obtained with 24 assets, 75% with 36 assets. In other words, 75% of the maximum effectiveness is achieved with fewer than half the maximum number of assets. It is highly unlikely that such quantities of assets would be available for employment at any particular time. However, these results are entirely dependent on the specific parameters used and our simple asset mix.

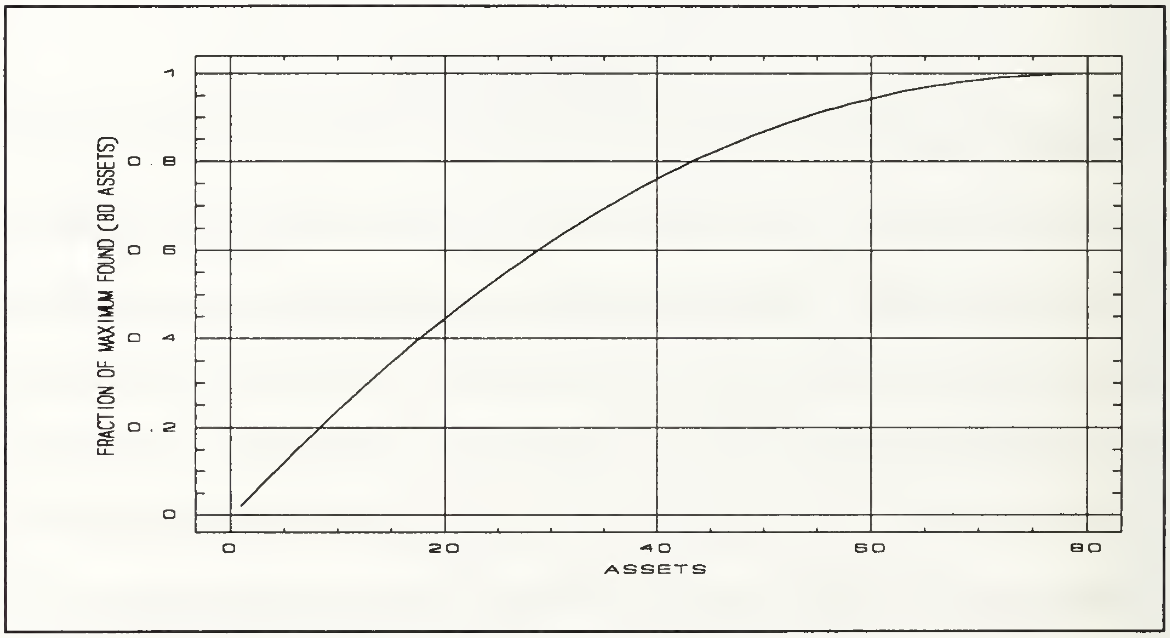


Figure 7 Fraction of maximum value found (at 80 assets) vs assets

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

In this thesis we have demonstrated that simulated annealing can be employed to find near-optimal locations for interdiction assets relative to a network with stochastic flows that are determined by a simulation. Our approach also demonstrated an application of this type of model to explore the relationship between the capabilities of interdiction assets, their number, and the resulting effect on the overall effectiveness of the interdiction effort. Although our model uses a simple representation of interdiction assets, combinations of assets, and the geographic, operational and political constraints which would normally be used to restrict feasible asset locations in the drug interdiction problem, we believe that the results demonstrate this methodology's viability for development into the type of analytic tool described in Chapter I, Section B.

The primary obstacle to further use of this methodology in counter-narcotics operational analysis and planning is the questionable reliability and limited amount of information available on smuggling activities. The credibility of results from this type of model, including the validity of SOAR, is highly dependent on the accuracy of information used in constructing the route network, and assigning costs to smugglers and parameters to assets. The suspect reliability of smuggling data will make it difficult to assess this credibility, short of actually employing operational assets and observing the resulting effects on smuggling and drug use. Even this level of verification would not necessarily provide an accurate measure of credibility since the targets of drug interdiction are the only true source of the information required, and they are not likely to come forward with such details.

B. AREAS FOR FURTHER RESEARCH

The next logical step in the development of an analytic tool useful to the counter-narcotics program is to apply the methodology explored in this thesis, or the model presented itself, to an expanded problem. Such an expansion should include all primary cocaine smuggling regions (Atlantic/Caribbean, Pacific, and Southwest Border), constraints reflecting the geographic and political considerations for asset locations, and operational inputs, such as budget feasible asset combinations and capability restrictions of assets. These constraints could easily be included in a subroutine which tests proposed asset moves for feasibility. Analysis of the results from an expanded problem will provide a more realistic evaluation of the utility that may be derived from this type of tool.

Expanding the size of the problem produces a major drawback in the use of the model developed in this thesis, extensive computer run times. With a network of only eleven routes, the five asset runs described in our results averaged seven hours each on the SUN SPARC 1+ workstation. Adding routes to the problem will significantly increase the run time of SOAR. Furthermore, our testing used only one trial of SOAR to obtain each new objective function value, while future testing should use the average of multiple trials to reduce the variability of the simulation results. This will increase run times even more, by approximately a multiple of the number of trials. For these reasons, analysis of the SOAR model to optimize performance, or translation into a more efficient programming language, and the use of high speed computers would be beneficial to future efforts.

A final consideration involves the variety of measures of effectiveness (MOEs) being used by drug interdiction agencies, as discussed in Chapter III, Section B.1. Development of a well-defined, quantifiable MOE for the entire drug interdiction program would be very valuable to future analysis. The MOE produced by the SOAR model for our optimization, total cost to the smugglers, relies heavily on information which may not be particularly accurate, as would be the case for any MOE that reflects the goals of the interdiction program as a whole. Continued intelligence efforts to gather accurate information on illegal drug smuggling activities and improvements in the timeliness of such data will help in defining an overall MOE and assessing the credibility of results from analytic tools used in counter-narcotics planning, and will make the drug interdiction program more effective.

A. MODEL INPUT AND OUTPUT

A. INPUT DATA SETS

1. ANNEAL DATA

a. Variables

Variable name	Description
STEPSIZE	Step size for the annealing algorithm in miles. Real.
STEPSIZEMIN	Minimum step size for the algorithm in miles. Real.
STEPSIZELOW	Step size in fine search for optimum value in miles. Real.
BETA	Control parameter for annealing. Adjusted to control the acceptance/rejection ratio. Real.
S	The stopping rule for the algorithm. This number of consecutive rejections stops the algorithm. Integer.
ALPHA	Parameter used to decrement the estimate of the optimal value and step size. Adjusted to control the speed of cooling. Typically between 0.01 and 0.2. Real.

GUESS	Inital estimate of the optimal objective function value. Real.
BIGN	The number of steps to be taken at each level of cooling. Integer.

b. Sample data set

```
INPUT PARAMETERS FOR THE ANNEALING ALGORITHM

STEPSIZE (MILES)   = 75.0
MIN STEP SIZE      = 40.0
SMALL STEP SIZE    =  5.0
CONTROL PARAMETER = 1.5
STOPPING RULE      = 100
ALPHA              = 0.1
GUESS AT MAXIMUM   = 100000000.00
STEPS PER LEVEL    = 1000
```

2. SOAR DATA

a. Variables

Variable name	Description
NUMMETHODS	Number of methods for smuggling drugs. Integer.
NUMPHASES	Number of phases. Integer.
NUMROUTES	Number of routes available. Integer.
NUMTRIALS	Number of times the analysis period is to be simulated. Reported results will be averaged over the trials. Integer.
ENDTIME	Number of days to be analyzed, not including the runin period.Integer.

RUNIN	Number of days to run the simulation before commencing the analysis. Integer.
IX	Seed for random number generator. Integer.
DRUGCOST	The cost at the source of a kilogram of cocaine. Real.
EXSHIPMENTINTVL	Expected time between shipments. Real.
EXSHIPMENTSIZE	Expected shipment size. Real.
METHODNAME(M)	The name of drug smuggling method M. Character.
CAPCOST(M)	The cost to the smuggler of an unsuccessful shipment using method M. Does not include the cost of the drug or the cost associated with the route. Real.
CAPACITY(M)	Maximum amount of drug that may be shipped by method M. Real.

b. Sample data set

```
METHODS  PHASES    ROUTES    TRIALS  RUNIN    ENDTIME    MEMORY      SEED
    3        2         3         2       120       60       0.1       7243
DRUGNAME      DRUGCOST   SHIPMEAN SHIPSIZE   DAILY AMT
COCAINE          7500.0      0.71      250.0     350.0
METHOD       RISK COMP RISK EXP   SEIZE COST MAX SHIP
AIR          1200000.0       2.0  200000.0     2000.0
SEA          1600000.0       2.0   40000.0    16000.0
LAND           10000.0       2.0    5000.0       50.0
   01
   61
```

3. ROUTES DATA

a. *Variables.*

Variable name	Description
ROUTENAME(R)	The name of route R. Character.
ROUTECOST(R)	The cost to the smuggler for using route R, incurred whether or not the shipment is successful. Real.
ROUTEMETHOD(R)	The index of the smuggling method that is used on route R. Integer. (1=Air,2=Sea,3=Land).
ROUTELOC(R)	The index of the geographic area of route R. Integer. (1=Atlantic,2=Pacific, 3=Southwest Border).
FIRST(R)	The index of the first point of route R. Integer.
NEXT(R,P)	The index of the point following P on route R. Integer.

b. *Sample data set.*

```
ROUTENR   ROUTENAME    ROUTECOST    ROUTEMETHOD  ROUTELOC
            POINTS
     1    MONA PASS      16000.00        2     1
            1    10     11    38

     2     WINDWARD      16000.00        2     1
            2    12     13    14    37

     3      YUCFLA1      16000.00        2     1
            3    15     36

     4      YUCALA1      16000.00        2     1
            3    15     35

     5      YUCTEX1      16000.00        2     1
            3    15     32

     6      YUCFLA2      16000.00        2     1
            4    15     36

     7      YUCFLA3      16000.00        2     1
            4    15     35

     8      YUCTEX2      16000.00        2     1
            4    15     32

     9         CUBA      20000.00        1     1
            3    36

    10      YUCALA2      20000.00        1     1
            7    34

    11      YUCTEX3      20000.00        1     1
            7    31
```

4. ASSET DATA

a. Variables.

Variable name	Description
NUMASSETS	Total number of assets, mobile and fixed. Integer.
NUMASSETTYPES	Total number of asset types. Integer.
ASSETNAME(A)	The name of asset A. Character.
LATASSET(A)	The latitude of asset A. Real.
LONASSET(A)	The longitude of asset A. Real.
ASSETTYPE(A)	Index of the type of asset A, for example, 1=air,2=ship,3=land, 4=aerostat balloon. Integer.
ASSETLOC(A)	Index of the geographic location of asset A. Same as ROUTELOC. Integer.
ASSETRANGE(AT,M)	Range for asset type AT versus smuggling method M for which the probability of interdiction is a constant. Real.
IPD(AT,M)	Probability of interdiction for asset type AT versus smuggling method M on a route, which is constant out to range ASSETRANGE. Real.

b. *Sample data set.*

```
TOTAL NUMBER OF ASSETS =     8

NUMBER OF ASSET TYPES =      4, PATROL AIR,SHIPS,LAND UNITS, AEROSTATS
ASSET       NAME        LATITUDE  LONGITUDE TYPE LOCALE
   1            PAIR1     16.00      75.85     1     1
   2            PAIR2     17.45      80.95     1     1
   3            SHIP1     19.00      68.00     2     1
   4            SHIP2     19.00      75.00     2     1
   5            SHIP3     21.98      86.18     2     1
   6   CUDLOE KEY FL      24.41      81.30     4     1
   7        MARFA TX      30.19     104.01     4     3
   8     GREAT EXUMA      23.33      75.47     4     1

ASSET RANGE VS METHOD
                         METHOD
ASSET             AIR         SEA         LAND
AIR              100.0       100.0        25.0
SHIPS             50.0        50.0         0.0
LAND              10.0         0.0         5.0
BALLOONS         200.0         0.0         0.0
P(INTERDICT) ASSET VS METHOD
                         METHOD
ASSET            AIR          SEA         LAND
AIR              0.1          0.1         0.1
SHIPS            0.1          0.1         0.0
LAND             0.1          0.0         0.1
BALLOONS         0.1          0.0         0.0
```

5. GEOGRAPHIC DATA

a. *Variables.*

<u>Variable name</u>	<u>Description</u>
POINTNAME(P)	The name of geographic point P. Character.
LAT(P)	The latitude of point P. Real.
LON(P)	The longitude of point P. Real.

b. Sample data set.

POINT	POINTNAME	LATITUDE	LONGITUDE
1	PT GALLINAS	12.15	71.45
2	RIO HACHA	11.30	73.00
3	SANTA MARTA	11.15	74.10
4	TURBO	8.00	76.45
5	BUENAVENTURA	3.58	77.50
6	TUMACO	1.45	78.45
7	MEDELLIN	6.10	75.47
8	BOGOTA	4.32	74.15
9	CALI	3.20	76.33
10	SMONAPASS	17.37	68.00
11	NMONAPASS	20.50	68.00
12	SWINDWARD	17.95	75.18
13	NWINDWARD	20.50	73.82
14	STRAIGHTS	22.72	76.91
15	YUCATAN	21.98	86.18
16	CENT MEXICO	25.00	103.00
17	NOGOLES AZ	31.20	110.55
18	BISBEE AZ	31.30	109.55
19	DOUGLAS AZ	31.20	109.30
20	YSLETA TX	31.42	106.18
21	PRESIDIO TX	29.33	104.23
22	DELRIO TX	29.21	100.52
23	DOLORES TX	27.42	99.47
24	BROWNSVILLE TX	25.95	97.30
25	SAN DIEGO CA	32.41	116.57
26	CALEXICO CA	32.41	115.30
27	??1 NM	31.40	108.50
28	??2 NM	31.40	108.25
29	FREEPORT TX	28.56	95.21
30	GALVESTON TX	29.18	94.48
31	HOUSTON TX	29.46	95.21
32	PORT LAVACA TX	28.36	96.38
33	SABINE TX	29.44	93.54
34	MOBILE AL	30.42	88.03
35	PENSACOLA FL	30.25	87.13
36	ST PETE FL	27.47	82.38
37	FLAMINGO FL	25.10	80.55
38	DAYTONA BCH FL	29.11	81.02
39	MIAMI FL	25.45	80.11
40	LOS ANGELES CA	34.00	118.15
41	BAJA TIP	22.64	109.82
42	S MEXICO	15.53	96.18
43	PACIFIC1	13.32	105.36
44	PACIFIC2	30.00	118.00
45	PACIFIC3	20.40	107.27
46	PACIFIC4	15.50	105.00

B. OUTPUT DATA SETS

1. SOAR OUTPUT

Output of the model includes an echo of the input parameters, and the following statistics:

1. Expected attempts per trial. The average number of shipments attempted during the period being analyzed.

2. Expected successes per trial. The average number of successful shipments during the analysis period.

3. Expected interdictions per trial. The average number of unsuccessful shipments during the analysis period. Expected attempts = Expected successes + Expected interdictions.

4. Success rate. The proportion of shipments that were successful.

5. Interdiction rate. The proportion of shipments that were unsuccessful.

6. Cost of incomplete shipments (in thousands). The average cost to the smuggler because of unsuccessful shipments, including the cost of the method (such as an airplane), the cost of the drug, and the cost of the route (such as gasoline).

7. Cost of completed shipments (in thousands). The average cost to the smuggler because of successful shipments, including the cost of the drug and the cost of the route.

8. Total cost to smugglers (in thousands). The sum of the cost of incomplete shipments and the cost of completed shipments.

9. For each drug, the quantity that the smugglers attempted to ship.

10. For each drug, the quantity that the smugglers successfully shipped.

11. For each drug, the quantity that the smugglers lost because of unsuccessful shipments.

12. For each route, the expected attempts, successes, and failures are reported.

13. For each phase and each route, the expected attempts, successes and failures are reported.

14. For each drug and each route, the expected quantities shipped, captured, etc.[Ref. 2: pp. 42,43]

2. ANNEALING MODEL OUTPUT

```
MAX TOTAL COST TO SMUGGLERS =   78047.95
         (IN THOUSANDS)

OPT VALUE FOUND IN        6630 STEPS
                           831 STEPS NOT ACCEPTED

      4195 INFEASIBLE MOVES FOUND


          FINAL LOCATIONS
          ASSET LATITUDE LONGITUDE
          PAIR1    22.715    84.834
          PAIR2    23.539    77.752
          SHIP1    20.728    83.596
          SHIP2    20.333    86.613
          SHIP3    21.687    68.579
  CUDLOE KEY FL    24.410    81.300
       MARFA TX    30.190   104.010
   GREAT EXUMA     23.330    75.470

FINAL PROBABILITY OF INTERDICTION BY ROUTE
ROUTE     ROUTENAME    PROBINTERDICT
    1      MONA PASS       0.1774
    2       WINDWARD       0.2130
    3        YUCFLA1       0.3206
    4        YUCALA1       0.3176
    5        YUCTEX1       0.3176
    6        YUCFLA2       0.2910
    7        YUCFLA3       0.2879
    8        YUCTEX2       0.2879
    9           CUBA       0.2249
   10        YUCALA2       0.2909
   11        YUCTEX3       0.1692

CPU TIME =      17704.3 SECONDS
MAX VALUE FOUND =      7.83917E+07
FINAL GUESS VALUE =      8.10845E+07

NEXT LOC SEED =   298087429
RUN COMPLETED
```

APPENDIX B. FORTRAN CODE

```
      PROGRAM ANNEAL

*   WRITTEN BY LT JAMES J. HENRY IV, USN
*   NAVAL POSTGRADUATE SCHOOL, CODE 360
*   OPERATIONS ANALYSIS CURRICULUM

*
*      PROGRAM VARIABLES
*
      INCLUDE 'COMMON.FOR'
      REAL PROBMOVE,
     &     TLAT(MAXASSETS),TLON(MAXASSETS),
     &     OBJVAL0,OBJVAL1,OBJVALM,OBJVALB,DELOBJ,
     &     V,P,TOTCOST,CPUTIME,
     &     A(2),DENOM,TARRAY(2)
      INTEGER K,LITTLEN,I,ROUTENR,MOVES,NOTMOVE,INFEAS
      LOGICAL FEASIBLE,ACCEPT,FINISH,GOODINPUT
*
*    CALL SUBROUTINE TO READ IN THE INITAL DATA
*

      CALL GETDATA(GOODINPUT)
      ISEED=IX
      ISEED1=IX
*
      IF(.NOT. GOODINPUT) STOP

      OBJVALM = GUESS
*
      DO 50 I=1,NUMASSETS
         TLAT(I) = LATASSET(I)
         TLON(I) = LONASSET(I)
   50 CONTINUE

*
*    RUN THE SIMULATION WITH INITIAL DATA POINTS
*
      CALL SMUGSIM(TLAT,TLON,TOTCOST)
      OBJVAL0 = TOTCOST
      OBJVALB = OBJVAL0
      IF(OBJVALB .GT. GUESS) GUESS = 1.5 * OBJVALB

*
*    BEGIN THE ANNEALING
*
      MOVES = 0
      NOTMOVE = 0
      INFEAS = 0
      FINISH = .FALSE.
      K = 0
      LITTLEN = 0
```

```
  100 CONTINUE

*   FIND NEW LOCATION FOR ALL ASSETS EXCEPT
*   BALLOONS (TYPE 4)
          DO 140 I = 1,NUMASSETS
                IF(ASSETTYPE(I) .NE. 4) THEN
  120                 CONTINUE
                            CALL LNORPC(ISEED1,A,2)
                            DENOM = SQRT(A(1)**2 + A(2)**2)
                            TLAT(I) = LATASSET(I) + DELR*A(1)/DENOM
                            TLON(I) = LONASSET(I) + DELR*A(2)/DENOM

*      CHECK FOR FEASIBILITY
                            IF(ASSETLOC(I) .EQ. 1) THEN
                                 CALL LANTCHECK(TLAT(I),TLON(I),FEASIBLE)
                            ELSEIF(ASSETLOC(I) .EQ. 2) THEN
                                 CALL PACCHECK(TLAT(I),TLON(I),FEASIBLE)
                            ELSE
                                 CALL SWBCHECK(TLAT(I),TLON(I),FEASIBLE)
                            ENDIF
                            IF(.NOT. FEASIBLE) INFEAS = INFEAS + 1

                      IF(.NOT. FEASIBLE) GO TO 120
                ENDIF
  140     CONTINUE
*
*   RUN THE SIMULATION WITH NEW DATA POINTS
          CALL SMUGSIM(TLAT,TLON,TOTCOST)
          OBJVAL1 = TOTCOST
          DELOBJ = OBJVAL1 - OBJVAL0
*         ADJUST MAX VALUE GUESS IF REQUIRED
          IF(OBJVAL1 .GT. OBJVALB) OBJVALB = OBJVAL1
          IF(OBJVALB .GT. GUESS) GUESS = 1.5 * OBJVALB
          IF(OBJVALB .GT. OBJVALM) OBJVALM = GUESS
*
*         DETERMINE WHETHER OR NOT TO ACCEPT THE MOVE
          IF(DELOBJ .GE. 0.0) THEN
                ACCEPT = .TRUE.
          ELSE
                CK = OBJVALM - OBJVAL0
                IF(CK .EQ. 0.0) CK = 0.000001
                P = EXP(BETA * DELOBJ / CK)
                CALL LRNDPC(ISEED1,V,1)
                IF(P .GE. V) THEN
                      ACCEPT = .TRUE.
                ELSE
                      ACCEPT = .FALSE.
                      K = K + 1
                      NOTMOVE = NOTMOVE + 1
                ENDIF
          ENDIF
          IF(ACCEPT) THEN
                COUNT = 0
                DO 160 I = 1,NUMASSETS
                      LATASSET(I) = TLAT(I)
                      LONASSET(I) = TLON(I)
  160           CONTINUE
                MOVES = MOVES + 1
                OBJVAL0 = OBJVAL1
                LITTLEN = LITTLEN + 1
```

```
          ENDIF
          IF(K .EQ. S)THEN
              DELROLD = DELR
              DELR = DELRLOW
          ELSEIF(K .GE. (2 * S)) THEN
              FINISH = .TRUE.
          ELSEIF(K .GT. S .AND. ACCEPT) THEN
              DELR = DELROLD
          ENDIF

          IF(LITTLEN .GE. BIGN) THEN
             OBJVALM = OBJVALM - ALPHA * (OBJVALM - OBJVALB)
             DELR = DELR - ALPHA * (DELR - DELRMIN)
          ENDIF
          IF(OBJVALM .LT. OBJVALB) OBJVALM = OBJVALB


       IF(.NOT. FINISH) GO TO 100
       CLOSE(55)

*    WRITE THE RESULTS
       OPEN(75,FILE='ANNEAL.OUT')

       WRITE(75,520) OBJVAL0/1000.0
   520 FORMAT(1X,'MAX TOTAL COST TO SMUGGLERS = ',F10.2)
       WRITE(75,530)
   530 FORMAT(10X,'(IN THOUSANDS)')

       WRITE(75,500)MOVES
   500 FORMAT(IX,'OPT VALUE FOUND IN ',I10,' STEPS')

       WRITE(75,50I)NOTMOVE
   50I FORMAT(I9X,I10,' STEPS NOT ACCEPTED')

       WRITE(75,*)
       WRITE(75,510)INFEAS
   510 FORMAT(IX,I10,' INFEASIBLE MOVES FOUND')
       WRITE(75,*)

       WRITE(75,*)
       WRITE(75,*)
       WRITE(75,534)
   534 FORMAT(11X,'FINAL LOCATIONS')
       WRITE(75,535)
   535 FORMAT(1IX,'ASSET',' LATITUDE ','LONGITUDE ')
       DO 550 I=1,NUMASSETS
          WRITE(75,540)ASSETNAME(I),LATASSET(I),LONASSET(I)
   540    FORMAT(1X,A15,F10.3,F10.3)
   550 CONTINUE

       WRITE(75,*)
       WRITE(75,589)
   589 FORMAT('FINAL PROBABILITY OF INTERDICTION BY ROUTE')
       WRITE(75,590)
   590 FORMAT('ROUTE',5X,'ROUTENAME',4X,'PROBINTERDICT')
       DO 600 ROUTENR = 1, NUMROUTES
          WRITE(75,610)ROUTENR,ROUTENAME(ROUTENR),
     &                  PROBINTERDICT(ROUTENR,1)
   610    FORMAT(1X,I4,5X,A10,5X,F8.4)
   600 CONTINUE
```

```
      CPUTIME = DTIME(TARRAY)
      WRITE(75,*)
      WRITE(75,*)' CPU TIME = ',CPUTIME,' SECONDS'
      WRITE(75,*)' MAX VALUE FOUND = ',MAXNOW
      WRITE(75,*)' FINAL GUESS VALUE = ',OBJVALM
      WRITE(75,*)
      WRITE(75,*) ' NEXT LOC SEED = ',ISEED1
      WRITE(75,*) ' RUN COMPLETED'
      CLOSE(75)

      STOP
      END

*******    SUBROUTINES TO CHECK FEASIBLE REGIONS    ******************

      SUBROUTINE LANTCHECK(LAT,LON,FEASIBLE)
*
      REAL LAT,LON
      LOGICAL FEASIBLE
*
      FEASIBLE = .FALSE.
      IF(LON .LE. 87.0 .AND. LON .GE.67.0 .AND.
     &    LAT .LE. 25.0 .AND. LAT .GE. 14.0) FEASIBLE = .TRUE.
      RETURN
      END
*********************************************************************

      SUBROUTINE PACCHECK(LAT,LON,FEASIBLE)
*
      REAL LAT,LON
      LOGICAL FEASIBLE
*
      FEASIBLE = .FALSE.
*
      IF(LAT .LE. 0.0) THEN
         FEASIBLE = .FALSE.
      ELSEIF(LON .LE. 120.0 .AND. LON .GE. 118.691) THEN
         IF(LAT .LE. 33.773) FEASIBLE = .TRUE.
      ELSEIF(LON .GE. 118.0) THEN
         IF(LAT .LE. 32.50) FEASIBLE = .TRUE.
      ELSEIF(LON .GE. 115.50) THEN
         IF(LAT .LE. (-132.70 - 1.40*LON)) FEASIBLE = .TRUE.
      ELSEIF(LON .GE. 113.00) THEN
         IF(LAT .LE. (-64.40 + .80*LON)) FEASIBLE = .TRUE.
      ELSEIF(LON .GE. 107.00) THEN
         IF(LAT .LE. (-69.1667 + .8333*LON)) FEASIBLE = .TRUE.
      ELSEIF(LON .GE. 84.50) THEN
         IF(LAT .LE. (-39.4444 + .5556*LON)) FEASIBLE = .TRUE.
      ELSEIF(LON .GE. 79.00) THEN
         IF(LAT .LE. (-15.5455 + .2727*LON)  .AND.
     &           LAT .GE. (121.5 - 1.5*LON)) FEASIBLE = .TRUE.
      ENDIF
      RETURN
      END
*********************************************************************

      SUBROUTINE SWBCHECK(LAT,LON,FEASIBLE)
*
      REAL LAT,LON
      LOGICAL FEASIBLE
```

```
*
      FEASIBLE = .FALSE.
*
      IF(LON .LE. 117.13 .AND. LON .GE. 115.0) THEN
         IF(LAT .GE. (33.74 - .0094*LON)) FEASIBLE = .TRUE.
      ELSEIF(LON .GE. 111.0) THEN
         IF(LAT .GE. (-7.015 + .345*LON)) FEASIBLE = .TRUE.
      ELSEIF(LON .GE. I08.295) THEN
         IF(LAT .GE. (33.742I - .0222*LON)) FEASIBLE = .TRUE.
      ELSEIF(LON .GE. 106.37) THEN
         IF(LAT .GE. 31.742) FEASIBLE = .TRUE.
      ELSEIF(LON .GE. 105.0) THEN
         IF(LAT .GE. (-51.18 + .7796*LON)) FEASIBLE = .TRUE.
      ELSEIF(LON .GE. 104.474) THEN
         IF(LAT .GE. (-173.537 + 1.9449*LON)) FEASIBLE = .TRUE.
      ELSEIF(LON .GE. I03.474) THEN
         IF(LAT .GE. (-38.3616 + .6510*LON)) FEASIBLE = .TRUE.
      ELSEIF(LON .GE. 103.36) THEN
         IF(LAT .GE. 29.0) FEASIBLE = .TRUE.
      ELSEIF(LON .GE. I02.73I) THEN
         IF(LAT .GE. (166.54II - I.3307*LON)) FEASIBLE = .TRUE.
      ELSEIF(LON .GE. 101.462) THEN
         IF(LAT .GE. 29.837) FEASIBLE = .TRUE.
      ELSEIF(LON .GE. 100.747) THEN
         IF(LAT .GE. (-72.6813 + I.0098*LON)) FEASIBLE = .TRUE.
      ELSEIF(LON .GE. 99.64) THEN
         IF(LAT .GE. (-104.1222 + 1.3225*LON)) FEASIBLE = .TRUE.
      ELSEIF(LON .GE. 99.00) THEN
         IF(LAT .GE. (-168.6709 + 1.9703*LON)) FEASIBLE = .TRUE.
      ELSEIF(LON .GE. 97.I33) THEN
         IF(LAT .GE. (1.7858 + .2485*LON)) FEASIBLE = .TRUE.
      ENDIF
      RETURN
      END

*******    SMUGSIM  SUBROUTINE    ***********************************

      SUBROUTINE SMUGSIM(TLAT,TLON,TOTCOST)
C       SMUGGLERS' SIMULATION - 2/3/87
*       ADAPTED FROM RAND CORPORATION SIMULATION OF ADAPTIVE
*       RESPONSE: A MODEL OF DRUG INTERDICTION. [Ref. 2]

C INSTALLATION REMARKS:
C
C       YOU'LL ALSO NEED TO SELECT "SIZING PARAMETERS" LARGE ENOUGH
C       TO HANDLE YOUR ANALYSIS, BUT NOT SO LARGE AS TO MAKE THE
C       PROGRAM TOO LARGE TO RUN ON YOUR MACHINE.  SEE THE BEGINNING
C       OF COMMON.FOR FOR PARAMETERS.

C***********************************************************************
C PROGRAM VARIABLES:

      INCLUDE 'COMMON.FOR'
      REAL TLAT(MAXASSETS),TLON(MAXASSETS)
      INTEGER*4 T,R

C***********************************************************************
C     INITIALIZE THE DATA COLLECTION ARRAYS.

      DO 30, R=1,MAXROUTES
```

```
          AMOUNTATTEMPTED(R) = 0.
          AMOUNTSUCCEEDED(R) = 0.
          ATTEMPTS(R) = 0.
          SUCCESSES(R) = 0.
          DO 20, THISPHASE = 1,MAXPHASES
               ATTEMPTSBYPHASE(R,THISPHASE) = 0.
               SUCCESSESBYPHASE(R,THISPHASE) = 0.
   20     CONTINUE
   30 CONTINUE

      SUCCESSCOSTS=0.0
      FAILURECOSTS=0.0

C         SET UP THE TABLE OF WEIGHTS FOR PAST SHIPMENTS.
          KMEMORY = ALOG(MEMORYVALUE)/(-LONGPAST)
      DO 40, T=0,LONGPAST
          EXPTABLE(T) = EXP(-KMEMORY*REAL(T))
   40 CONTINUE

*     CALL THE SUBROUTINE TO COMPUTE ROUTE PROBABILITIES BASED ON
*     ASSET LOCATIONS
      CALL PROBCOMP(TLAT,TLON)

C         CALL THE SUBROUTINE THAT DOES THE RUN IN.
      CALL PEACE

C         DO EACH TRIAL.
      DO 50, NTRIAL=1,NUMTRIALS
         CALL SIMULATE
   50 CONTINUE

* COMPUTE OUTPUT TO ANNEALING ALGORITHM

C        INITIALIZE THE TOTALS.
         TOTATTEMPTED=0.
         TOTSHIPPED=0.
         TOTATTEMPTS=0.
         TOTSUCCESSES=0.
         TOTSUCCESSCOST=0.
         TOTFAILURECOST=0.

C        COMPUTE THE TOTAL NUMBER OF ATTEMPTS, SUCCESSES, COSTS, ETC.
         DO 30, R=1,NUMROUTES
             TOTATTEMPTS = TOTATTEMPTS + ATTEMPTS(R)
             TOTSUCCESSES = TOTSUCCESSES + SUCCESSES(R)
             TOTATTEMPTED = TOTATTEMPTED +
     &                        AMOUNTATTEMPTED(R)
             TOTSHIPPED = TOTSHIPPED + AMOUNTSUCCEEDED(R)
             SUCCESSCOSTS = SUCCESSCOSTS +
     &                        AMOUNTSUCCEEDED(R) * DRUGCOST
             FAILURECOSTS = FAILURECOSTS +
     &                        (AMOUNTATTEMPTED(R)-
     &                               AMOUNTSUCCEEDED(R)) *
     &                        DRUGCOST
   30    CONTINUE
             TOTSUCCESSCOST=TOTSUCCESSCOST+SUCCESSCOSTS
             TOTFAILURECOST=TOTFAILURECOST+FAILURECOSTS

C        GET THE AVERAGE NUMBER OF ATTEMPTS, SUCCESSES, COSTS, ETC.
C        PER TRIAL.
```

```
        TOTATTEMPTS = TOTATTEMPTS/NUMTRIALS
        TOTSUCCESSES = TOTSUCCESSES/NUMTRIALS
        TOTSUCCESSCOST = TOTSUCCESSCOST/NUMTRIALS
        TOTFAILURECOST = TOTFAILURECOST/NUMTRIALS
        TOTCOSTS = TOTSUCCESSCOST + TOTFAILURECOST

      RETURN
      END
C*********************************************************************

C*********************************************************************

        SUBROUTINE COMPFACT(RNUMERATOR,RDENOMINATOR,R)
C       GET THE NUMERATOR AND DENOMINATOR OF THE "R" FACTOR, WHICH
C       WILL BE USED TO INCREASE THE PROBABILITY OF INTERDICTION
C       ON ROUTES WITH HIGHER THAN AVERAGE TRAVEL.

C************************************************************************
C PROGRAM VARIABLES:

      INCLUDE 'COMMON.FOR'
        INTEGER*4 R,RNUMERATOR,RDENOMINATOR,S

C************************************************************************

        RNUMERATOR = 0
        RDENOMINATOR = 0
        DO 10, S=0,LONGPAST
            RDENOMINATOR = RDENOMINATOR + PASTSHIPMENTS(R,S)
   10   CONTINUE
        DO 20, S=0,RECENTPAST
            RNUMERATOR = RNUMERATOR+PASTSHIPMENTS(R,S)
   20   CONTINUE
        RETURN
        END
C*********************************************************************

C*********************************************************************

        SUBROUTINE GETDATA(GOODINPUT)
C       READ IN THE INPUT DATA.

C************************************************************************
C PROGRAM VARIABLES:

      INCLUDE 'COMMON.FOR'
      REAL    STEPSIZEM
      INTEGER*4 DAY1,DAY2,DAYN,M,N,TEMP,TEMP2,
     &          P,ROUTENR,I,J,PTS(MAXPTS),
     &          METHOD,
     &          POINT,TYPE,ASSET
      CHARACTER*15 POINTNAME(MAXPOINTS)
      LOGICAL      GOODINPUT
      LOGICAL TEMPIF

C************************************************************************

C       GOODINPUT WILL INDICATE WHETHER THE DATA WAS CLEAN AND THE
C       SIMULATION SHOULD BE RUN.
        GOODINPUT = .TRUE.
```

```
*
      OPEN(55,FILE='ANNEAL.DAT')
*
      READ(55,*)
      READ(55,*)
      READ(55,4010)STEPSIZEM
      READ(55,4010)STEPSIZEMIN
      READ(55,4010)STEPSIZELOW
 4010 FORMAT(20X,F5.1)
*     APPROXIMATION OF STEP SIZE IN DEGREES
      DELR = STEPSIZEM/60.0
      DELRMIN = STEPSIZEMIN/60.0
      DELRLOW = STEPSIZELOW/60.0
*
      READ(55,4020)BETA
 4020 FORMAT(20X,F5.2)
*
      READ(55,4030)S
 4030 FORMAT(20X,I5)
*
      READ(55,4040)ALPHA
 4040 FORMAT(20X,F5.3)
*
      READ(55,4050) GUESS
 4050 FORMAT(20X,F15.2)
*
      READ(55,4060) BIGN
 4060 FORMAT(20X,I10)
*
      CLOSE(55)


C       READ IN THE OVERALL SOAR SIMULATION DATA.
      OPEN(76, FILE='INPUT.DAT')
      READ(76,*)
      READ (76,5010) NUMMETHODS,NUMPHASES,NUMROUTES,
     &                NUMTRIALS,RUNIN,ENDTIME,MEMORYVALUE,IX
 5010 FORMAT (6(I5,4X),F10.5,2X,I5)
C       CHECK WHETHER TOO MANY METHODS HAVE BEEN REQUESTED.
      TEMPIF = (NUMMETHODS .GT. MAXMETHODS)
      CALL WRTERROR(TEMPIF,GOODINPUT)

C       CHECK WHETHER TOO MANY PHASES HAVE BEEN REQUESTED.
      TEMPIF = (NUMPHASES .GT. MAXPHASES)
      CALL WRTERROR(TEMPIF,GOODINPUT)

C       CHECK WHETHER TOO MANY ROUTES HAVE BEEN REQUESTED.
      TEMPIF = (NUMROUTES .GT. MAXROUTES)
      CALL WRTERROR(TEMPIF,GOODINPUT)

C       CHECK WHETHER TOO MANY DAYS HAVE BEEN REQUESTED.
      TEMPIF = (ENDTIME .GT. MAXDAYS)
      CALL WRTERROR(TEMPIF,GOODINPUT)

C       MAKE SURE THE INITIAL SEED IS ODD.  (IN CASE WE RUN ON A SUN.)
      IX = IX / 2
      IX = IX * 2 + 1

C       READ IN THE DRUG RELATED DATA RECORDS.
      READ(76,*)
```

```
      READ (76,5020) DRUGNAME,DRUGCOST,EXSHIPMENTINTRVL,
     &               EXSHIPMENTSIZE,DAILYAMOUNT
 5020 FORMAT (A10,4F10.5)
C       READ IN THE METHOD RELATED RECORDS.
      TEMP = NUMMETHODS
      IF (TEMP .GT. MAXMETHODS) TEMP = MAXMETHODS
      READ(76,*)
      DO 40, M=1,TEMP
          READ (76,5030) METHODNAME(M),
     &                   RISKCOMP(M),RISKCOMPEXP(M),CAPCOST(M),
     &                   CAPACITY(M)
 5030     FORMAT(A5,5X,4F10.5)
   40 CONTINUE
      IF (NUMMETHODS .GT. TEMP) THEN
          DO 50, M=TEMP+1,NUMMETHODS
              READ (76,5030)
   50     CONTINUE
      ENDIF

C       READ IN THE DAYS WHEN EACH PHASE ENDS.  SET UP THE VECTOR
C       INDICATING WHICH PHASE IS IN EFFECT FOR EACH DAY.
      DAY1 = 0
      TEMP = NUMPHASES
      IF (TEMP .GT. MAXPHASES) TEMP = MAXPHASES
         DO 70, N=1,TEMP
            READ (76,5040) DAY2
 5040       FORMAT (I5)
            TEMP2 = DAY2
            IF (TEMP2 .GT. MAXDAYS) TEMP2 = MAXDAYS
            IF (TEMP2 .GE. DAY1) THEN
                WRITE (77,6016) N,TEMP2
 6016           FORMAT (8X,'PHASE ',I2,' LASTS THROUGH DAY ',I4)
                DO 60, DAYN=DAY1,TEMP2
                    CURRENTPHASE(DAYN) = N
   60           CONTINUE
                DAY1 = TEMP2 + 1
            ENDIF
   70    CONTINUE

         CLOSE(76)

* READ IN THE NETWORK ROUTES AND ROUTE DATA

      OPEN(96,FILE='ROUTES.DAT')
      READ(96,*)
      READ(96,*)
      DO 250 ROUTENR = 1,NUMROUTES
         DO 210 P = 1, MAXPOINTS
              NEXT(ROUTENR,P) = 0
  210    CONTINUE
         READ(96,5075)ROUTENAME(ROUTENR),ROUTECOST(ROUTENR),
     &                ROUTEMETHOD(ROUTENR),ROUTELOC(ROUTENR)
 5075    FORMAT(9X,A10,3X,F10.2,2X,I5,I5)

         DO 220 I=1,MAXPTS
              PTS(I)=0
  220    CONTINUE
         READ(96,5080)FIRST(ROUTENR),(PTS(I),I=1,MAXPTS)
 5080    FORMAT(10X,9I5)
         P=FIRST(ROUTENR)
```

```
         J=1
  240    IF(P .NE. 0) THEN
              NEXT(ROUTENR,P) = PTS(J)
              P = NEXT(ROUTENR,P)
              J = J + 1
         GO TO 240
         ENDIF
  250 CONTINUE
      CLOSE(96)

* READ IN THE ASSET DATA

      OPEN(98,FILE='ASSET.DAT')
      READ(98,5300)NUMASSETS
      READ(98,5300)NUMASSETTYPES
 5300 FORMAT(25X,I5)
C       CHECK WHETHER TOO MANY ASSETS HAVE BEEN REQUESTED.
      TEMPIF = (NUMASSETS .GT. MAXASSETS)
      CALL WRTERROR(TEMPIF,GOODINPUT)

C       CHECK WHETHER TOO MANY ASSET TYPES HAVE BEEN REQUESTED.
      TEMPIF = (NUMASSETTYPES .GT. MAXASSETTYPES)
      CALL WRTERROR(TEMPIF,GOODINPUT)
      READ(98,*)
      DO 350 ASSET = 1, NUMASSETS
         READ(98,5320)ASSETNAME(ASSET),
     &                    LATASSET(ASSET),LONASSET(ASSET),
     &                    ASSETTYPE(ASSET),ASSETLOC(ASSET)
 5320    FORMAT(5X,A15,2(F10.3),2(I5))
  350 CONTINUE
      READ(98,*)
      READ(98,*)
      READ(98,*)
      READ(98,*)
      DO 360 TYPE=1,NUMASSETTYPES
         READ(98,5325)(RANGE(TYPE,METHOD),METHOD=1,NUMMETHODS)
 5325    FORMAT(15X,3(F5.1,5X))
  360 CONTINUE
      READ(98,*)
      READ(98,*)
      READ(98,*)
      READ(98,*)
      DO 390 TYPE=1,4
         READ(98,5330)(IPD(TYPE,METHOD),METHOD=1,3)
 5330    FORMAT(15X,3(F5.3,5X))
  390 CONTINUE
      CLOSE(98)

* READ IN THE GEOGRAPHICAL DATA

      OPEN(95,FILE='GEOGR.DAT')
      READ(95,*)
  392 READ(95,5400,END=395)POINT,POINTNAME(POINT),LAT(POINT),LON(POINT)
 5400    FORMAT(1X,I5,5X,A15,5X,F7.3,5X,F7.3)
      GO TO 392
  395 CONTINUE
      CLOSE(95)

      RETURN
      END
```

```
C*********************************************************************

C*********************************************************************

        SUBROUTINE INITSIM
C       INITIALIZE FOR THE CURRENT SAMPLE POINT.

C************************************************************************
C PROGRAM VARIABLES:

      INCLUDE 'COMMON.FOR'
        INTEGER*4 D,R
        REAL RANDNM

C************************************************************************

C       SET THE SHIPMENT COUNTER TO ZERO.
        NUMSHIPMENT = 0

C       DETERMINE WHEN THE NEXT SHIPMENT WILL OCCUR.
        CALL LRNDPC(IX,RANDNM,1)
        NEXTEVENT = ENDTIME + 1.0
        NEXTSHIPMENT = - EXSHIPMENTINTRVL * ALOG(RANDNM)
        IF (NEXTSHIPMENT .LT. NEXTEVENT) THEN
            NEXTEVENT = NEXTSHIPMENT
        ENDIF

C       GET THE PAST FROM THE LONG RUN IN.
        DO 30, D=0,LONGPAST
            DO 20, R=1,NUMROUTES
                PASTSHIPMENTS(R,D) = PEACESHIPMENTS(R,D)
                PASTFAILURES(R,D) = PEACEFAILURES(R,D)
   20       CONTINUE
   30   CONTINUE
        RETURN
        END
C*********************************************************************

C*********************************************************************

        SUBROUTINE PEACE
C       DO THE INITIAL RUN IN.

C************************************************************************
C PROGRAM VARIABLES:

      INCLUDE 'COMMON.FOR'
        REAL AMOUNT,PROBCAUGHT,RFACTOR,TEMPTIME,RANDNM,ACTUALRISKCOMP
        INTEGER*4 D,R,RDENOMINATOR,RNUMERATOR,T,TRIPS
        LOGICAL TRIPSUCCESS

C************************************************************************

C       DETERMINE THE TIME OF THE FIRST SHIPMENT.
        NEXTEVENT = RUNIN + 1.0
        CALL LRNDPC(IX,RANDNM,1)
        NEXTSHIPMENT = -EXSHIPMENTINTRVL * ALOG(RANDNM)
        IF (NEXTSHIPMENT .LT. NEXTEVENT) THEN
            NEXTEVENT = NEXTSHIPMENT
        ENDIF
```

```
C       INITIALIZE THE ARRAYS DESCRIBING THE PAST.
        DO 230, D=0,LONGPAST
            DO 220, R=1,NUMROUTES
                PASTSHIPMENTS(R,D) = 0
                PASTFAILURES(R,D) = 0
  220       CONTINUE
  230   CONTINUE

C       FOR EACH DAY OF RUNIN...
        DO 100, DAYNOW=1,RUNIN
            THISPHASE = 1

C           SHIFT THE ARRAYS DESCRIBING THE PAST.
            DO 20, R=1,NUMROUTES
                DO 10, D=LONGPAST,1,-1
                    PASTSHIPMENTS(R,D) = PASTSHIPMENTS(R,D-1)
                    PASTFAILURES(R,D) = PASTFAILURES(R,D-1)
   10           CONTINUE
                PASTSHIPMENTS(R,0) = 0
                PASTFAILURES(R,0) = 0
   20       CONTINUE

C           LOOP THROUGH THE DAYS SHIPMENTS.
   30       IF (NEXTEVENT .GE. DAYNOW + 1.0) GO TO 100

C               GET THE AMOUNT OF THE NEXT SHIPMENT.
                AMOUNT = EXSHIPMENTSIZE

C               SELECT THE ROUTE TO BE USED.
                CALL SELROUTE(R,TRIPS,AMOUNT,ACTUALRISKCOMP)

C               COMPUTE THE NUMERATOR AND DENOMINATOR OF THE
C               "R" FACTOR.
                CALL COMPFACT(RNUMERATOR,RDENOMINATOR,R)

C               FOR EACH TRIP REQUIRED TO GET AMOUNT SHIPPED...
                DO 70, T=1,TRIPS

C                   COMPUTE THE "R" FACTOR.
                    RFACTOR = 1.0
                    IF (RDENOMINATOR .GT. 0.0) THEN
                        RFACTOR = RNUMERATOR/RDENOMINATOR
                        TEMPTIME = NEXTEVENT
                        IF (TEMPTIME .GT. RECENTPAST) THEN
                            IF (TEMPTIME .GT. LONGPAST)
     &                          TEMPTIME = LONGPAST
                            RFACTOR = RFACTOR * TEMPTIME/RECENTPAST
                        ENDIF
                    ENDIF
                    IF (RFACTOR .LT. 1.0) RFACTOR = 1.0

C                  COMPUTE THE PROBABILITY OF INTERDICTION.
                   IF (PROBINTERDICT(R,THISPHASE).GE..9999) THEN
                       PROBCAUGHT = 1.0
                   ELSE
                        PROBCAUGHT = 1.0 - EXP(RFACTOR*ALOG(1.0 -
     &                           PROBINTERDICT(R,THISPHASE)))
                   ENDIF

C                  DETERMINE WHETHER THE TRIP WAS SUCCESSFUL.
```

```
                     CALL LRNDPC(IX,RANDNM,1)
                     TRIPSUCCESS = (RANDNM .GE. PROBCAUGHT)

C                     DO THE BOOKKEEPING.  (NOT VERY EXTENSIVE
C                     DURING THE RUN IN.)
                      PASTSHIPMENTS(R,0) = PASTSHIPMENTS(R,0) + 1
                      IF (.NOT. TRIPSUCCESS)
     &                    PASTFAILURES(R,0) = PASTFAILURES(R,0) + 1
                      RNUMERATOR = RNUMERATOR + 1
                      RDENOMINATOR = RDENOMINATOR + 1
   70             CONTINUE

C                 GET THE TIME AND TYPE OF THE NEXT SHIPMENT.
                  CALL LRNDPC(IX,RANDNM,1)
                  NEXTSHIPMENT = NEXTEVENT -
     &                               EXSHIPMENTINTRVL * ALOG(RANDNM)
                  NEXTEVENT = RUNIN + 1.0
                  IF (NEXTSHIPMENT .LT. NEXTEVENT) THEN
                      NEXTEVENT = NEXTSHIPMENT
                  ENDIF
              GO TO 30
  100     CONTINUE

C         SAVE THE LAST LONGPAST DAYS FOR USE INITIALIZING EACH TRIAL.
          DO 130, D=0,LONGPAST
              DO 120, R=1,NUMROUTES
                  PEACESHIPMENTS(R,D)=PASTSHIPMENTS(R,D)
                  PEACEFAILURES(R,D)=PASTFAILURES(R,D)
  120         CONTINUE
  130     CONTINUE
          RETURN
          END
C*********************************************************************


C*********************************************************************

          SUBROUTINE SELROUTE(RCHOSEN,TRIPS,AMOUNT,ACTUALRISKCOMP)
C         SELECT THE ROUTE FOR THE NEXT SHIPMENT.

C************************************************************************
C PROGRAM VARIABLES:

        INCLUDE 'COMMON.FOR'
          REAL AMOUNT,CUMPROB,ROUTEPROB,COSTROUTE(MAXROUTES),
     &         ACTUALRISKCOMP,PROBCAUGHT(MAXROUTES),
     &         TEMPNUMERATOR(MAXROUTES),TEMPDENOMINATOR(MAXROUTES),
     &         TOTCOST,WEIGHT,TEMPRISKCOMP(MAXROUTES)
          INTEGER*4 RCHOSEN,TRIPS,RMETHOD,R,S

C************************************************************************

C         INITIALIZE THE NUMERATOR AND DENOMINATOR FOR EACH ROUTE.
        DO 10, R=1,NUMROUTES
           TEMPNUMERATOR(R) = 0.0
           TEMPDENOMINATOR(R) = 0.0
           COSTROUTE(R) = 0.0
   10   CONTINUE

C         FOR EACH DAY TO BE CONSIDERED, ADD IN ITS CONTRIBUTION.
```

```
      DO 30, S=0,LONGPAST
         WEIGHT = EXPTABLE(S)
         DO 20, R=1,NUMROUTES
              TEMPDENOMINATOR(R) =
     &              TEMPDENOMINATOR(R) + WEIGHT*PASTSHIPMENTS(R,S)
              TEMPNUMERATOR(R) = TEMPNUMERATOR(R) +
     &              WEIGHT*PASTFAILURES(R,S)
   20    CONTINUE
   30 CONTINUE

C       FOR EACH ROUTE, COMPUTE THE PERCEIVED PROBABILITY OF BEING
C       CAPTURED AND HENCE THE EXPECTED COST OF USING THE ROUTE.
C       THE PROBABILITY A ROUTE WILL BE CHOSE WILL BE PROPORTIONAL
C       TO THE INVERSE EXPECTED COST OF USING THE ROUTE, SO GET THE
C       TOTAL OF THE INVERSE EXPECTED COSTS OF USING EACH ROUTE.
        TOTCOST = 0.0
        DO 40, R=1,NUMROUTES
            RMETHOD = ROUTEMETHOD(R)
            TRIPS = INT(AMOUNT/CAPACITY(RMETHOD) + 0.999)
            IF (TEMPDENOMINATOR(R) .GT. 0.001) THEN
                PROBCAUGHT(R) = TEMPNUMERATOR(R)/TEMPDENOMINATOR(R)
            ELSE
                PROBCAUGHT(R) = 0.0
            ENDIF
            IF (RISKCOMPEXP(RMETHOD) .LE. 0.0001) THEN
                TEMPRISKCOMP(R)=RISKCOMP(RMETHOD)
            ELSE
                TEMPRISKCOMP(R)=RISKCOMP(RMETHOD) *
     &                     ((2*PROBCAUGHT(R))**RISKCOMPEXP(RMETHOD))
            ENDIF
            COSTROUTE(R) = 1.0/(TRIPS*(PROBCAUGHT(R)*CAPCOST(RMETHOD)+
     &                       ROUTECOST(R) + TEMPRISKCOMP(R))+
     &                       PROBCAUGHT(R)*AMOUNT*DRUGCOST)
              TOTCOST = TOTCOST + COSTROUTE(R)
   40   CONTINUE

C       NOW CHOOSE THE ROUTE, WHERE THE PROBABILITY OF CHOOSING A
C       GIVEN ROUTE IS PROPORTIONAL TO THE INVERSE COST OF USING
C       THAT ROUTE.
        CALL LRNDPC(IX,ROUTEPROB,1)
      CUMPROB = 0.0
      R = 0
   50 CONTINUE
         R = R + 1
         CUMPROB = CUMPROB + COSTROUTE(R)/TOTCOST
      IF (CUMPROB .LT. ROUTEPROB) GO TO 50
      RCHOSEN = R
        RMETHOD = ROUTEMETHOD(RCHOSEN)
        TRIPS = INT(AMOUNT/CAPACITY(RMETHOD) + 0.999)
        ACTUALRISKCOMP=TEMPRISKCOMP(RCHOSEN)

        RETURN
        END
C*********************************************************************

C*********************************************************************

        SUBROUTINE SIMULATE
C       THIS SUBROUTINE PERFORMS THE SIMULATION FOR A SINGLE SAMPLE
C       POINT.
```

```
C***********************************************************************
C PROGRAM VARIABLES:

        INCLUDE 'COMMON.FOR'
          REAL AMOUNT,PROBCAUGHT,RFACTOR,TEMPTIME,RANDNM,ACTUALRISKCOMP,
     &       TIMESHIPPED(MAXSHIPMENTS)
          INTEGER*4 D,R,RDENOMINATOR,RNUMERATOR,T,TRIPS,
     &            ROUTEUSED(MAXSHIPMENTS)
          LOGICAL TRIPSUCCESS,SUCCESS(MAXSHIPMENTS)

C***********************************************************************

C       INITIALIZE FOR THIS TRIAL.
        CALL INITSIM

C       FOR EACH DAY...
        DO 100, DAYNOW=0,ENDTIME

C           GET THE POINTER INTO THE ARRAY OF INTERDICTION PROBABILITIES.
            THISPHASE = CURRENTPHASE(DAYNOW)

C           SHIFT THE PAST HISTORY ARRAYS.
            DO 20, R=1,NUMROUTES
                DO 10, D=LONGPAST,1,-1
                    PASTSHIPMENTS(R,D) = PASTSHIPMENTS(R,D-1)
                    PASTFAILURES(R,D) = PASTFAILURES(R,D-1)
   10           CONTINUE
                PASTSHIPMENTS(R,0) = 0
                PASTFAILURES(R,0) = 0
   20       CONTINUE

C           LOOP THROUGH THE EVENTS THAT HAPPEN TODAY.
   30       IF (NEXTEVENT .GE. DAYNOW + 1.0) GO TO 100

C               DETERMINE THE NEXT TYPE OF DRUG TO BE SHIPPED AND
C               HOW MUCH.
                AMOUNT = EXSHIPMENTSIZE

C               SELECT THE ROUTE.
                CALL SELROUTE(R,TRIPS,AMOUNT,ACTUALRISKCOMP)

C               GET THE NUMERATOR AND DENOMINATOR OF THE "R" FACTOR.
                CALL COMPFACT(RNUMERATOR,RDENOMINATOR,R)

C               MULTIPLE TRIPS MAY BE REQUIRED TO SHIP THE GIVEN
C               AMOUNT OF DRUG ON THE SELECTED ROUTE, DUE TO
C               CAPACITY CONSTRAINTS.  THE VARIABLE TRIPS CONTAINS
C               THE NUMBER OF TRIPS THAT WILL BE REQUIRED.  I EXPECT
C               THAT THIS VARIABLE WILL USUALLY BE CONTAIN A ONE
C               AND THAT AS A RESULT DO-LOOP 70 WILL USUALLY BE
C               EXECUTED ONLY ONCE.
                DO 70, T=1,TRIPS

C                   COMPUTE THE "R" FACTOR.
                    RFACTOR = 1.0
                    IF (RDENOMINATOR .GT. 0.0) THEN
                        RFACTOR = RNUMERATOR/RDENOMINATOR
                        TEMPTIME = NEXTEVENT
                        IF (TEMPTIME .GT. RECENTPAST) THEN
                            IF (TEMPTIME .GT. LONGPAST)
```

```
     &                         TEMPTIME = LONGPAST
                           RFACTOR = RFACTOR * TEMPTIME/RECENTPAST
                       ENDIF
                   ENDIF
                   IF (RFACTOR .LT. 1.0) RFACTOR = 1.0

C                  COMPUTE THE PROBABILITY OF INTERDICTION.
C                 COMPUTE THE PROBABILITY OF INTERDICTION.
                  IF (PROBINTERDICT(R,THISPHASE).GE..9999) THEN
                      PROBCAUGHT = 1.0
                  ELSE
                       PROBCAUGHT = 1.0 - EXP(RFACTOR*ALOG(1.0 -
     &                          PROBINTERDICT(R,THISPHASE)))
                  ENDIF

C                 DETERMINE WHETHER THE TRIP WAS SUCCESSFUL.
                  CALL LRNDPC(IX,RANDNM,1)
                  TRIPSUCCESS = (RANDNM .GE. PROBCAUGHT)

C                  DO THE REQUIRED BOOKKEEPING.
                   NUMSHIPMENT = NUMSHIPMENT + 1
                   SUCCESS(NUMSHIPMENT) = TRIPSUCCESS
                   TIMESHIPPED(NUMSHIPMENT) = NEXTEVENT
                   ROUTEUSED(NUMSHIPMENT) = R
                   ATTEMPTS(R) = ATTEMPTS(R) + 1.0
                   AMOUNTATTEMPTED(R) =
     &                 AMOUNTATTEMPTED(R) + AMOUNT/TRIPS
                   ATTEMPTSBYPHASE(R,THISPHASE) =
     &                 ATTEMPTSBYPHASE(R,THISPHASE)+1
                   IF (TRIPSUCCESS) THEN
                       SUCCESSCOSTS=SUCCESSCOSTS+ACTUALRISKCOMP+
     &                                                ROUTECOST(R)
                       SUCCESSES(R) = SUCCESSES(R) + 1.0
                       AMOUNTSUCCEEDED(R) =
     &                     AMOUNTSUCCEEDED(R) + AMOUNT/TRIPS
                       SUCCESSESBYPHASE(R,THISPHASE) =
     &                     SUCCESSESBYPHASE(R,THISPHASE) + 1
                   ELSE
                       PASTFAILURES(R,0) = PASTFAILURES(R,0) + 1
                       FAILURECOSTS=FAILURECOSTS+ACTUALRISKCOMP+
     &                             ROUTECOST(R) +
     &                             CAPCOST(ROUTEMETHOD(R))
                   ENDIF
                   PASTSHIPMENTS(R,0) = PASTSHIPMENTS(R,0) + 1
                   RNUMERATOR = RNUMERATOR + 1
                   RDENOMINATOR = RDENOMINATOR + 1
   70         CONTINUE

C             DETERMINE WHEN THE NEXT SHIPMENT OF THIS DRUG WILL BE.
              CALL LRNDPC(IX,RANDNM,1)
              NEXTSHIPMENT = NEXTEVENT -
     &                       EXSHIPMENTINTRVL * ALOG(RANDNM)

C             DETERMINE WHAT THE NEXT SHIPMENT WILL BE.
              NEXTEVENT = ENDTIME + 1.0
              IF (NEXTSHIPMENT .LT. NEXTEVENT) THEN
                  NEXTEVENT = NEXTSHIPMENT
              ENDIF
          GO TO 30
  100   CONTINUE
```

```
        RETURN
        END
C*********************************************************************

C*********************************************************************

        SUBROUTINE WRTERROR(ERRORCONDITION,GOODINPUT)
C       THIS SUBROUTINE WRITES THE ERROR MESSAGE, IF NEEDED.
*
C************************************************************************
C PROGRAM VARIABLES:

        LOGICAL ERRORCONDITION,GOODINPUT

C************************************************************************

        IF (ERRORCONDITION) THEN
            WRITE (77,6001)
 6001       FORMAT (' ***ERROR***')
            GOODINPUT = .FALSE.
        ENDIF
        RETURN
        END
C*********************************************************************


**********************************************************************
      SUBROUTINE PROBCOMP(TLAT,TLON)
*  THIS SUBROUTINE COMPUTES PROBABILITIES OF INTERDICTION ON
*  ROUTES AS A FUNCTION OF ASSET DISTANCE FROM ROUTE.
*  PROBABILITY OF INTERDICTION IS INPUT TO SMUGSIM.
*
      INCLUDE 'COMMON.FOR'
*
      REAL M1,M2,B1,B2,TEMPPI,LATINT,LONINT,DST,DEND,LENGTH,DIST,A,
     &     TLAT(MAXASSETS),TLON(MAXASSETS),GSDIS,FCTR
      INTEGER P,Q,R



*  COMPUTE PROBABILITY OF INTERDICTION FOR EACH ROUTE

      DO 405 R=1,NUMROUTES
         DO 400 N=1,NUMPHASES
              PROBINTERDICT(R,N) = 0.0
  400    CONTINUE
  405 CONTINUE

*  FOR EACH ROUTE COMPUTE EQUATIONS FOR ROUTE SEGMENTS
      DO 440 R=1,NUMROUTES
         P=FIRST(R)
         Q=NEXT(R,P)
  410    CONTINUE
              IF(LON(P) .NE. LON(Q)  .AND.
     &           LAT(P) .NE. LAT(Q))THEN
                 M1=(LAT(P) - LAT(Q))/
     &              (LON(P) - LON(Q))
                 M2=-1.0/M1
                 B1=LAT(P) - M1*LON(P)
              ENDIF
```

```
              TEMPPI=0.0
              DO 420 ASSET=1,NUMASSETS
                 IF(LON(P) .NE. LON(Q)   .AND.
     &              LAT(P) .NE. LAT(Q))THEN
                      B2=LATASSET(ASSET) - M2*LONASSET(ASSET)
                      LATINT=(B1*M2 - B2*M1)/(M2-M1)
                      LONINT=(B1-B2)/(M2-M1)
                 ELSEIF(LON(P) .EQ. LON(Q)) THEN
                      LATINT=LATASSET(ASSET)
                      LONINT=LON(P)
                 ELSE
                      LATINT=LAT(P)
                      LONINT=LONASSET(ASSET)
                 ENDIF

*   DETERMINE CLOSEST POINT BETWEEN ASSET AND ROUTE SEGMENT
                 DST=GSDIS(LON(P),LAT(P),
     &                     LONINT,LATINT)
                 DEND=GSDIS(LON(Q),LAT(Q),
     &                      LONINT,LATINT)
                 LENGTH=GSDIS(LON(P),LAT(P),
     &                     LON(Q),LAT(Q))
                 IF(DST .LE. LENGTH .AND. DEND .LE. LENGTH) THEN
                     DIST=GSDIS(LONASSET(ASSET),LATASSET(ASSET),
     &                          LONINT,LATINT)
                 ELSEIF(DST .LT. DEND) THEN
                     DIST=GSDIS(LONASSET(ASSET),LATASSET(ASSET),
     &                          LON(P),LAT(P))
                 ELSE
                      DIST=GSDIS(LONASSET(ASSET),LATASSET(ASSET),
     &                           LON(Q),LAT(Q))
                 ENDIF

*   COMPUTE PROBABILITIES (INDEPENDENCE ASSUMED0
                 IF(DIST .LE.
     &              RANGE(ASSETTYPE(ASSET),ROUTEMETHOD(R))) THEN
                    A = 1.0 - IPD(ASSETTYPE(ASSET),ROUTEMETHOD(R))

                 ELSE
                   IF(RANGE(ASSETTYPE(ASSET),ROUTEMETHOD(R)) .EQ. 0.0)
     &                RANGE(ASSETTYPE(ASSET),ROUTEMETHOD(R)) = 0.0001
                    FCTR=(RANGE(ASSETTYPE(ASSET),ROUTEMETHOD(R))-DIST)/
     &                      RANGE(ASSETTYPE(ASSET),ROUTEMETHOD(R))
                    A = 1.0 - IPD(ASSETTYPE(ASSET),ROUTEMETHOD(R))
     &                         * EXP(FCTR)
                 ENDIF
                 TEMPPI = 1.0 - (A * (1.0 - TEMPPI))
  420         CONTINUE
              DO 430 N=1,NUMPHASES
                 PROBINTERDICT(R,N) = 1.0 -(1.0 - TEMPPI)*
     &                           (1.0 - PROBINTERDICT(R,N))
  430         CONTINUE
              P = Q
              Q = NEXT(R,P)
          IF(Q .NE. 0) GO TO 410
  440 CONTINUE
      RETURN
      END
C*********************************************************************
      REAL FUNCTION GSDIS( X1, Y1, X2, Y2 )
```

```
*  FUNCTION COMPUTES THE GREAT CIRCLE DISTANCE IN MILES
*  BETWEEN TWO POINTS EXPRESSED IN LATITUDE AND LONGITUDE

      REAL*4       X1,Y1,X2,Y2
      REAL*4       RARC,RLAT1,RLAT2,RLON1,RLON2,RPD

*---LOCAL DATA INITIALIZATION
      DATA         RPD /0.1745329433017307E-01/

*---GREAT CIRCLE DISTANCE
*
*    INPUTS ARE TWO POINTS EXPRESSED AS (W. LONGITUDE, N. LATITUDE)
*--- CONVERT DEGREES TO RADIANS
      RLON1 = RPD * X1
      RLAT1 = RPD * Y1
      RLON2 = RPD * X2
      RLAT2 = RPD * Y2
*---SPHERICAL ARC LENGTH IN RADIANS

      ARGUMENT = (SIN(RLAT1)*SIN(RLAT2)
     &        +COS(RLAT1)*COS(RLAT2)*COS(RLON1-RLON2))

      IF(ARGUMENT .GT. 1.0) ARGUMENT = 1.0
      IF(ARGUMENT .LT. -1.0) ARGUMENT = -1.0
      RARC = ACOS(ARGUMENT)

*---ARC LENGTH IN STATUTE MILES WITH ROUGH CORRECTION FOR OBLATENESS
*    OBLATENESS CONTRIBUTES LESS THAN 0.25% CORRECTION.
*    IN U.S., DARC IS APPROXIMATELY 3959.0*RARC
*
      GSDIS = 3959.0E0*RARC

      RETURN
      END

*******     RANDOM NUMBER GENERATING SUBROUTINES  *********************
C    ADAPTED FROM LEWIS,ORAV,AND URIBE ENHANCED SIMULATION AND
C    STATISTICS PACKAGE [Ref. 27]
C    THIS PROGRAM WILL GENERATE A VECTOR OF NORMAL RANDOM VARIABLES
C    ACCORDING TO THE SINE-COSINE METHOD
C
     SUBROUTINE LNORPC(ISEED,A,N)
     INTEGER  N,I,IND,ISEED
     REAL  A(N),U(2),S,W,XSTAR
     DOUBLE PRECISION  PI
     DATA PI/3.14159265358979D0/
     IND = 1
     DO 100 I=1,N
             IND = -IND
        IF (IND.GE.0) GOTO 20
  10         CALL LRNDPC(ISEED,U,2,0,0)
        S =SQRT(-2*ALOG(U(1)))
        W = 2*PI*U(2)
        XSTAR = S*COS(W)
        A(I) = S*SIN(W)
        GOTO 100
  20         A(I) = XSTAR
 100      CONTINUE
     RETURN
     END
```

```
*
*
*
      SUBROUTINE LRNDPC (ISEED,U,N)
      INTEGER              N, I,ISEED
      REAL                 U(N)
      DOUBLE PRECISION     D31M1, DSEED, D31
C     D31M1=2**31 - 1
C     D31  =2**31
      DATA D31M1/2147483647.D0/
      DATA D31  /2147483648.D0/
      DSEED = DBLE(ISEED)

      DO 5 I=1,N
C        DSEED = DMOD(950706376.D0*DSEED,D31M1)
         DSEED = DMOD(16807.D0*DSEED,D31M1)
         U(I) = DSEED / D31
    5 CONTINUE

      ISEED = INT(DSEED)
      RETURN
      END


*******     COMMON.FOR

C    SET PAMETERS:
      INTEGER*4         LONGPAST, RECENTPAST, MAXDAYS,
     &                  MAXMETHODS, MAXPHASES, MAXROUTES, MAXSHIPMENTS,
     &                  MAXASSETS,MAXASSETTYPES,MAXPOINTS,
     &                  MAXPTS

      PARAMETER        (LONGPAST=120, RECENTPAST=20,
     &                  MAXDAYS=730,
     &                  MAXMETHODS=3, MAXPHASES=12, MAXROUTES=100,
     &                  MAXSHIPMENTS=6000,MAXASSETS=100,
     &                  MAXASSETTYPES=4,MAXPOINTS=50,MAXPTS=8)


C    COMMON VARIABLES:

C        REAL VARIABLES:
      REAL              AMOUNTATTEMPTED(MAXROUTES),
     &                  AMOUNTSUCCEEDED(MAXROUTES),
     &                  ATTEMPTS(MAXROUTES),
     &                  ATTEMPTSBYPHASE(MAXROUTES,MAXPHASES),
     &                  CAPCOST(MAXMETHODS),
     &                  CAPACITY(MAXMETHODS),
     &                  DAILYAMOUNT,
     &                  DRUGCOST,EXPTABLE(0:LONGPAST),
     &                  EXSHIPMENTINTRVL,
     &                  EXSHIPMENTSIZE,
     &                  FAILURECOSTS,KMEMORY,MEMORYVALUE,
     &                  NEXTEVENT,NEXTSHIPMENT,
     &                  PROBINTERDICT(MAXROUTES,MAXMETHODS),
     &                  RISKCOMP(MAXMETHODS),
     &                  RISKCOMPEXP(MAXMETHODS),
     &                  ROUTECOST(MAXROUTES),
     &                  SUCCESSCOSTS,
     &                  SUCCESSES(MAXROUTES),
```

```
     &                  SUCCESSESBYPHASE(MAXROUTES,MAXPHASES),
     &                  LAT(MAXPOINTS),LON(MAXPOINTS),
     &                  LATASSET(MAXASSETS),LONASSET(MAXASSETS),
     &                  DELR,DELRMIN,DELRLOW,
     &                  BETA,ALPHA,RANGE(MAXASSETTYPES,MAXMETHODS),
     &                  IPD(MAXASSETTYPES,MAXMETHODS),GUESS

C        INTEGER VARIABLES:
      INTEGER*4         CURRENTPHASE(0:MAXDAYS),DAYNOW,ENDTIME,NTRIAL,
     &                  NEXTEVENTTYPE,NUMMETHODS,NUMPHASES,
     &                  NUMROUTES,NUMSHIPMENT,NUMTRIALS,
     &                  PASTSHIPMENTS(MAXROUTES,0:LONGPAST),
     &                  PASTFAILURES(MAXROUTES,0:LONGPAST),
     &                  ROUTEMETHOD(MAXROUTES),RUNIN,
     &                  THISPHASE,
     &                  PEACESHIPMENTS(MAXROUTES,0:LONGPAST),
     &                  PEACEFAILURES(MAXROUTES,0:LONGPAST),
     &                  NUMASSETS,ROUTELOC(MAXROUTES),
     &                  ASSETLOC(MAXASSETS),
     &                  ASSETTYPE(MAXASSETS),NUMASSETTYPES,
     &                  S,NEXT(MAXROUTES,MAXPOINTS),
     &                  FIRST(MAXROUTES),BIGN

C        INTEGER VARIABLES:
      INTEGER*4         IX,ISEED

C     CHARACTER VARIABLES:
      CHARACTER*10      METHODNAME(MAXMETHODS)

      CHARACTER*12      ROUTENAME(MAXROUTES)
      CHARACTER*15      ASSETNAME(MAXASSETS)

      COMMON   AMOUNTATTEMPTED,AMOUNTSUCCEEDED,ATTEMPTS,
     &                  ATTEMPTSBYPHASE,
     &                  CAPCOST,
     &                  CAPACITY,
     &                  DAILYAMOUNT,
     &                  DRUGCOST,EXPTABLE,
     &                  EXSHIPMENTINTRVL,
     &                  EXSHIPMENTSIZE,
     &                  FAILURECOSTS,KMEMORY,MEMORYVALUE,
     &                  NEXTEVENT,NEXTSHIPMENT,
     &                  PROBINTERDICT,
     &                  RISKCOMP,
     &                  RISKCOMPEXP,
     &                  ROUTECOST,
     &                  SUCCESSCOSTS,
     &                  SUCCESSES,
     &                  SUCCESSESBYPHASE,
     &                  LAT,LON,
     &                  LATASSET,LONASSET,
     &                  DELR,DELRMIN,DELRLOW,
     &                  BETA,ALPHA,RANGE,IPD,GUESS,
     &                  CURRENTPHASE,DAYNOW,ENDTIME,NTRIAL,
     &                  NEXTEVENTTYPE,NUMMETHODS,NUMPHASES,
     &                  NUMROUTES,NUMSHIPMENT,NUMTRIALS,
     &                  PASTSHIPMENTS,
     &                  PASTFAILURES,
     &                  ROUTEMETHOD,RUNIN,
     &                  THISPHASE,
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&                   PEACESHIPMENTS,
&                   PEACEFAILURES,
&                   NUMASSETS,ROUTELOC,
&                   ASSETLOC,
&                   ASSETTYPE,NUMASSETTYPES,
&                   S,NEXT,FIRST,BIGN,
&                   IX,ISEED,
&                   METHODNAME,
&                   ROUTENAME,ASSETNAME
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